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Since its inception in 1991, SERDP has responded to the Department of Defense's (DoD) highest priority requirements by supporting just under 300 environmental science and technology projects. These projects have enabled DoD installations to meet their environmental responsibilities using cost-effective and innovative methods. During FY 1999, SERDP continued to play a critical role in the development of science and technology that supports the DoD's environmental security goals. While the projects represent only a small selection of the many innovative and groundbreaking projects supported by SERDP, they show the breadth and depth of the Program and highlight the most significant accomplishments of FY 1999. Moreover, these accomplishments demonstrate the potential cost savings while simultaneously maintaining mission readiness when new technologies become fully implemented.

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DoD EPA DOE SERDP
Strategic Environmental Research and Development Program

# ANNUAL REPORT TO CONGRESS

## Fiscal Year 1999

DEPARTMENT OF DEFENSE UNITED STATES OF AMERICA

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

March 2000

DoD EPA DOE SERDP
Strategic Environmental Research and Development Program

# ANNUAL REPORT TO CONGRESS — FISCAL YEAR 1999

## FROM THE STRATEGIC ENVIRONMENTAL RESEARCH AND DEVELOPMENT PROGRAM

**March 2000**

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# PREFACE

The Strategic Environmental Research and Development Program (SERDP) was established by Title 10 U.S.C. §§2901-2904. SERDP addresses environmental matters of concern to the Department of Defense and the Department of Energy. It is a Department of Defense program planned, managed, and executed in full partnership with the Department of Energy and the Environmental Protection Agency with participation by numerous other Federal and non-Federal organizations.

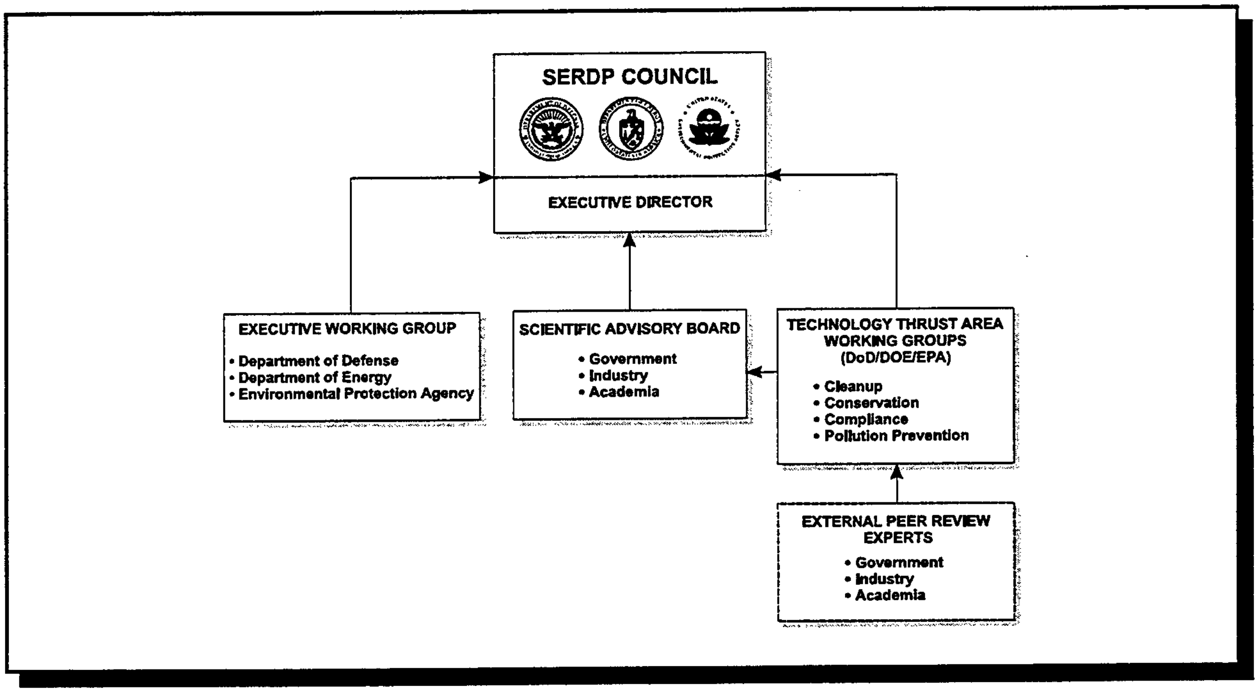


**Figure 1. SERDP Organization**

This report provides a summary of SERDP's activities and most significant accomplishments during fiscal year 1999, its plans for fiscal year 2000, and new initiatives to be addressed in fiscal year 2001.

# SERDP Council

**Established by law, SERDP's multi-agency Council ensures integrated, non-duplicative research.**

Title 10, U.S.C. §2902 established the Strategic Environmental Research and Development Program Council to oversee management of SERDP. Specifically, this Council prescribes policies and procedures to implement the Program and may enter into contracts, grants, and other agreements in accordance with other applicable law to carry out the purposes of SERDP. Congress intended the Council to be a multi-agency membership body to promote maximum exchange of information and to minimize duplication of environmental related research, development, and demonstration activities through close coordination with the military departments and Defense agencies; the Department of Energy; the Environmental Protection Agency; the National Oceanic and Atmospheric Administration; the National Aeronautics and Space Administration; other departments and agencies of the Federal, State, and local governments; and other organizations engaged in environmental related research.

**DoD and DOE alternate as co-chairs.**

Consistent with the SERDP statute and with facilitating multi-agency cooperation, the Secretary of Defense designates a member of the Council as chairperson for each odd-numbered fiscal year and the Secretary of Energy designates a member of the Council to serve as chair for each even-numbered year. Membership during the fiscal year does not remain constant. Following are the SERDP Council members who served during a portion of or for the entire FY 1999. A list of current SERDP Council members may be found on the SERDP website (www.serdp.org/general/about/organization/ organization.html).

**Council Members - FY 1999**

**Dr. Delores Etter (Chair)**
Department of Defense
Research and Engineering

**Colonel Rick Drawbaugh**
Department of the Air Force
Environment, Safety, and Occupational Health Technologies

**Brigadier General Thomas Gioconda**
Department of Energy
Defense Programs

**Ms. Sherri Goodman**
Department of Defense
Environmental Security

**Captain Michael Grimes**
U.S. Coast Guard
Research and Development

**Dr. Carolyn Huntoon**
Department of Energy
Environmental Management

**Ms. Catherine Kominos**
Department of the Army
Research and Laboratory Management

**Dr. Martha Krebs**
Department of Energy
Energy Research

**Mr. Henry Longest, II**
Environmental Protection Agency
Research and Development

**Ms. Norine Noonan**
Environmental Protection Agency
Research and Development

**Mr. James Owendoff**
Department of Energy
Environmental Management

**Dr. John Parmentola**
Department of the Army
Research and Laboratory Management

**General Joseph Ralston**
Department of Defense
Joint Chiefs of Staff

**Dr. Victor Reis**
Department of Energy
Defense Programs

**Dr. Fred Saalfeld**
Department of the Navy
Naval Research

**Mr. Bradley Smith** *(non-voting member)*
Strategic Environmental Research and Development Program

# SERDP Scientific Advisory Board

The SERDP Scientific Advisory Board (SAB), established in accordance with the SERDP statute, assures the Council's primary focus on technical quality. The SAB may make recommendations to the Council regarding technologies, research, projects, programs, activities, and, if appropriate, funding within the scope of the SERDP.

**SAB members ensure the Council's focus on technical quality.**

The SAB is composed of no more than 14 members who are jointly appointed by the Secretary of Defense and the Secretary of Energy in consultation with the Administrator of the Environmental Protection Agency. During the year, membership changed periodically due to the retirement of two members and the passing of another. To ensure a program that is congruent with the Administration's goals, there are two statutory members of the SAB. They are the Science Advisor to the President, or his/her designee, and the Administrator of the National Oceanic and Atmospheric Administration, or his/her designee. Similarly, to ensure that regional and global environmental issues are appropriately addressed in SERDP, at least one member should represent the interests of State governments and one member should represent environmental public interest groups.

The *Annual Report to Congress - Fiscal Year 1999* by the SERDP SAB reviews the specific actions taken and recommendations made by the SAB during fiscal year 1999. The report was provided to Congress in March 2000.

**Scientific Advisory Board Members - FY 1999**

**Dr. Braden Allenby**
AT&T

**Dr. Patrick R. Atkins**
Aluminum Company of America

**Dr. Mary Barber**
The Ecological Society of America

**Dr. Rosina M. Bierbaum**
Office of the Science Advisor to the President

**Dr. Paul Busch** (†)
Malcolm Pirnie, Inc.

**Dr. Steven Clifford**
National Oceanic and Atmospheric Administration

**Dr. Kenneth Dickson**
University of North Texas

**Dr. Raymond C. Loehr**
University of Texas at Austin

**Dr. Perry L. McCarty**
Stanford University

**Dr. Roger O. McClellan**
Chemical Industry Institute of Toxicology

**Dr. Jean'ne M. Shreeve (Vice Chair)**
University of Idaho

**Dr. C. Herb Ward (Chair)**
Rice University

**Mr. Robert S. Winokur**
National Oceanic and Atmospheric Administration

**Mr. Randolph Wood**
Nebraska Department of Environmental Quality

**Dr. Lily Young**
Rutgers University

(†) deceased

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# I. EXECUTIVE SUMMARY

## SERDP Overview

Congress established SERDP in Public Law 101-510 (Title 10, U.S.C., §§2901-2904) as a Department of Defense (DoD) program planned and executed in partnership with the Department of Energy (DOE) and the Environmental Protection Agency (EPA). As the DoD's corporate environmental Science and Technology (S&T) program, SERDP fully leverages complementary programs found within the Army, Navy, and Air Force, as well as those of the DOE and the EPA. Measures have been implemented to take full advantage of the intrinsic capabilities of the participating organizations. This feature makes SERDP unique; SERDP truly can tap the vast technical resources of the Federal laboratory infrastructure to meet the needs of our most pressing environmental matters of concern.

The mission of SERDP can be found in this authorizing congressional language. Specifically, the four purposes of SERDP are to:

**SERDP addresses DoD and congruent DOE environmental matters of concern**

- Address environmental matters of concern to the DoD and the DOE through support for basic and applied research and development of technologies that can enhance the capabilities of the Departments to meet their environmental obligations;

- Identify research, technologies, and other information developed by the DoD and the DOE for national defense purposes that would be useful to governmental and private organizations involved in the development of energy technologies and of technologies to address environmental restoration, waste minimization, hazardous waste substitution, and other environmental concerns and to share such research, technologies, and other information with such governmental and private organizations;

- Furnish other governmental organizations and private organizations with data, enhanced data collection capabilities, and enhanced analytical capabilities for use by such organizations in the conduct of environmental research; and

- Identify technologies developed by the private sector that are useful for DoD and DOE defense activities concerning environmental restoration, hazardous and solid waste minimization and prevention, and hazardous material substitution and provide for the use of such technologies in the conduct of such activities.

DoD environmental concerns may be divided into two broad categories of concerns:

- Those that impact training, logistics, and combat operations, and

- Those that have cost and performance impacts on the supporting infrastructure.

Both categories can negatively impact the Department's ability to perform its primary mission of maintaining military readiness for national defense.

# SERDP Program Goals

SERDP is a "requirements-driven" program that directly responds to defense requirements generated by the Services and sanctioned by the Deputy Under Secretary of Defense for Environmental Security (DUSD/ES). SERDP remained dedicated to solving DoD environmental problems by providing a forum for environmental technology partnership. This partnership, led by members of the SERDP Council, seeks to:

- Resolve environmental concerns in ways that enhance military operations, improve military systems effectiveness, and help ensure the safety of personnel; and

- Support technology and process development that reduce operational and life cycle costs, including those associated with environmental cleanup and costs of full compliance with environmental laws and regulations.

The SERDP Council ensures that the partnership focuses on the mission needs of the DoD. In the course of addressing DoD's highest priority environmental needs in the areas of Cleanup, Compliance, Conservation, and Pollution Prevention, SERDP also has sought opportunities to help solve other significant national and international environmental problems through the application of DoD's technical capabilities, analytical systems, and information.

SERDP achieves its goals by:

- Identifying and supporting programs of basic and applied research and development to:
  - Accelerate cost-effective cleanup of contaminated defense sites;
  - Facilitate full compliance with environmental laws and regulations at reduced cost
  - Enhance training, testing, and operational readiness through prudent land management and conservation measures
  - Reduce or eliminate defense industrial waste streams through aggressive pollution prevention programs that strongly encourage use of non-hazardous, non-toxic, non-polluting, and other environmentally sound materials, substances, and processes.

- Promoting the effective exchange of information regarding environmentally related research and development activities.

- Ensuring that SERDP research and development (R&D) activities complement, but do not duplicate, Tri-Service R&D programs and other ongoing activities.

**SERDP focuses on DoD mission needs that are environmentally related.**

- Providing appropriate access to data under the control of, or otherwise available to, the Departments of Defense and Energy that is relevant to environmental matters.

- Facilitating the transfer of unclassified DoD and DOE environmental information and technology to other sectors of society that might be able to use them to advance national environmental objectives.

- Emphasizing multi-service, inter-departmental research and development projects and using the unique capabilities of the partnering Federal agencies, private industry, and academia to solve the Departments' environmental problems.

# Research Framework

## Environmental Technology Development

**SERDP allocates resources toward 6.1, 6.2, and/or 6.3 projects as needed.**

Figure I-1 illustrates SERDP's role in the DoD environmental technology development process. While many of the Armed Services' Environmental Quality programs are specifically focused on either basic research, applied research, or advanced technology development, SERDP has the flexibility to perform under all of these research categories. This allows SERDP to place scarce resources against the highest priorities and most intractable problems faced by DoD. The efforts collectively facilitate acceptance by Defense Systems Program Executive Officers (PEO) and transition to the commercial sector.

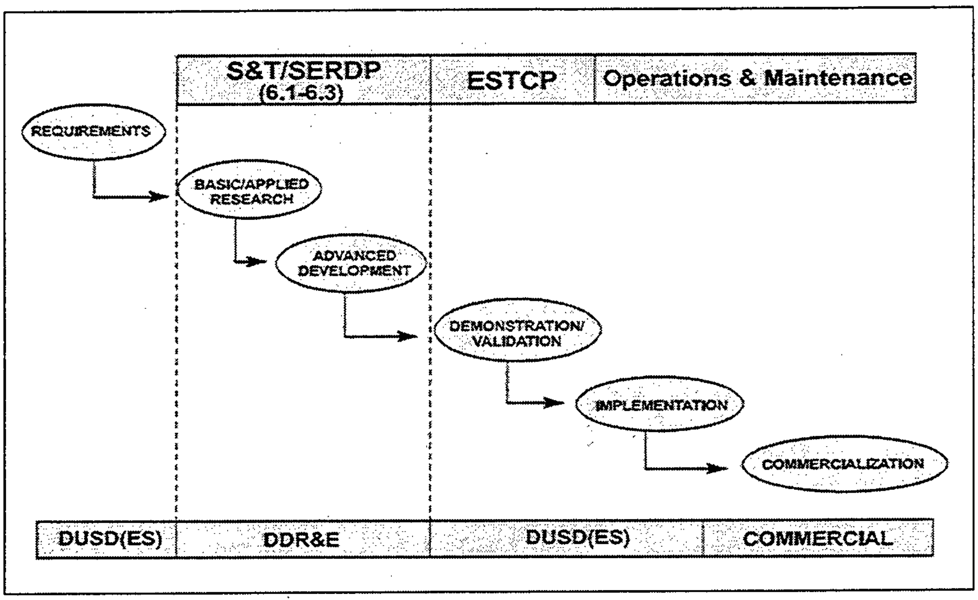



**Figure I-1. Environmental Technology Development Process**

The multi-Agency aspect of SERDP encourages leveraging and interaction with other environmental programs to identify and solve defense specific needs, extend applications of defense information to others, and build on existing science and technology to derive more useable and cost-effective approaches for achieving reductions in environmental risks.

Figure I-2 represents the research taxonomy that defines the SERDP Program. The primary areas of emphasis were developed in response to user community needs for science and technology required to accomplish the military mission in an environmentally compliant manner. Accordingly, these Thrust Areas - Cleanup, Compliance, Conservation and Pollution Prevention - are consistent with the focus of the Office of the Deputy Under Secretary of Defense for Environmental Security [ODUSD(ES)], and they directly parallel the four pillars of the Tri-Service Environmental Quality Technology programs. The SERDP Thrust Areas also correspond to those identified in the National Environmental Technology Strategy.

| CLEANUP | COMPLIANCE | CONSERVATION | POLLUTION PREVENTION |
|---|---|---|---|
| Unexploded Ordnance Detection | Air | Maintain/Enhance Training and Testing Capability | Air |
| Site Characterization and Monitoring | Liquids | Natural Resources Stewardship | Liquids |
| Remediation | Solids | Cultural Resources Stewardship | Solids |
| Risk Assessment Technologies | | Noise | Modeling and Measurement |

**Figure I-2. Research Taxonomy**

## Search for Innovation

SERDP seeks innovative ideas with commensurate technical risk. The SERDP Exploratory Development Program, or SEED, was initiated in FY 1999 to encourage submission of novel ideas to be demonstrated under a low-cost ($100,000 or less), short-term (one year), proof-of-concept study. SEED projects and the larger, longer-term Core efforts both respond to the highest priority needs as defined in published Statements of Need (SON). These SONs are released annually with a Federal Call for Proposals and a non-Federal Broad Agency Announcement. In search of world-class research, SERDP promotes direct participation from the private sector, including small and large businesses and academic institutions.

# Program Management and Oversight

## SERDP Council

### *Actions*

Multi-agency management and oversight of SERDP continues to be one of the clear strengths of the Program. Active participation by the members of the SERDP Council, and their designated representatives on the Executive Working Group (EWG) and Technology Thrust Area Working Groups (TTAWG), precludes duplication of effort, ensures quality Program content, and facilitates information transfer. Composed of programmatic and technical individuals who represent the three primary participating organizations, this tri-parte arrangement brings with it a breadth of knowledge and experience at several levels of management and technical expertise lending significant credibility to the Program.

**Multi-Agency management is a clear strength of the Program.**

On September 29, 1998, the SERDP Council approved the FY 1999 Program Plan and the FY 2000 Investment Plan, and codified a standing SERDP Strategic Guidance. For FY 1999, SERDP was appropriated $59.4 million. Six million dollars represented additions to the President's Budget Request (PBR) to fund two Congressional interest projects.

One year later on September 23, 1999, the Council again met to approve the FY 2000 Program and FY 2001 Investment Strategy. The PBR for FY 2000 was $53.5 million, however, Congressional support for the Program resulted in an appropriation of $58.5 million that included funding two additional specific interest projects. Funding for continuing SERDP projects and new start efforts is stable and has not changed significantly.

## Technical Strategy

For FY 1999, the SERDP Council directed the continuing pursuit of six avenues in planning and executing defense mission-relevant environmental research and development and an additional new avenue to increase innovation:

- ✔ Identify and fund major-impact, multi-agency environmental R&D programs to solve high-priority, mission readiness related concerns of DoD;
- ✔ Identify opportunities to accelerate existing DoD environmental quality R&D programs and fund those that address the highest priority concerns of the Department;
- ✔ Identify, leverage, adapt, and/or adopt existing technologies to address environmental concerns of DoD and DOE;
- ✔ Advance and use applicable state-of-the-art modeling and simulation capabilities to accomplish SERDP goals;
- ✔ Use the technical and research capabilities of the SERDP partners, including their unique data collection and analysis capabilities, as appropriate;
- ✔ Plan for a transition of successfully proven technologies to demonstration and validation or to commercialization and implementation; and
- ✔ Encourage high-risk, high-payoff novel approaches to resolve environmental problems through the use of low-cost, short-term, exploratory R&D efforts.

## Investment Strategy

With the advice of the SERDP Scientific Advisory Board, the SERDP Council annually determines the distribution of funding to the Thrust Areas. Figure I-3 depicts the percentage of Program funding trends for each technology Thrust Area from FY 1999 through FY 2004.

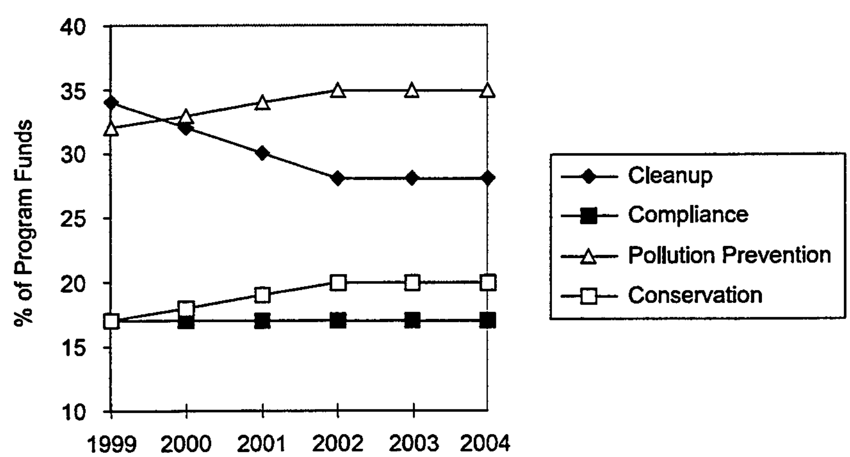



**Figure I-3. Funding Balance Across the SERDP Thrust Areas**

While forecasts are based on known or expected requirements and stated goals of the Services and ODUSD(ES), actual requirements for R&D may change from year to year. Consequently, these trends may not reflect actual investments, but are developed for planning purposes.

**Cleanup technologies continue to yield the highest returns on investment.**

**Cleanup:** In order to impact specific cleanup goals that DoD has set for the future, most technologies currently under development must be delivered to the field very soon. Accordingly, investments in cleanup generally are on a downward trend. This is part of the conscientious shift within the DoD from a cleanup posture to one of preventing pollution. Yet, there are two intractable and pervasive problems faced by DoD, unexploded ordnance and dense non-aqueous phase liquids that preclude a significant drop in cleanup technology investment. While the investment in Cleanup is expected to decrease over the next three years, it will not decrease as dramatically as proposed in past years. Without question, the return on investment continues to be high for cleanup technology development.

**DoD seeks to take a prevention-based posture.**

**Pollution Prevention:** A focused investment to eliminate future DoD waste streams will reduce sharply or eliminate the environmental consequences experienced in the past. The DoD promotes sustainable development and SERDP is a strong proponent of its tenets. SERDP invests significantly in new processes that support sustainability; we must work cooperatively and systematically to foster development without compromising the ability of future generations to meet their needs. Clearly the biggest returns in the future are expected by reducing or eliminating the generation of pollutants. Accordingly, an increase in Pollution Prevention technology investment is anticipated over the next three years.

**Research to reduce environmental impacts on DoD activities.**

**Compliance:** Current environmental regulations may preclude, or severely restrict, military training, operations, and manufacturing activities. SERDP efforts are directed at the various regulations, including the Clean Air Act, Safe Drinking Water Act, and others to reduce the costs and operational limitations associated with Notices of Violations claimed against our defense facilities and operational forces. While the promulgation of the Range Rule, Haze Rule, and additional restrictions under the Clean Air Act Amendments are indeed imminent, their impacts on DoD testing and training operations are not fully known. Barring identification of significant new regulatory requirements, funding for SERDP compliance-related technology development is anticipated to remain stable.

**SERDP supports efforts that promote responsible resource management**

**Conservation:** Conservation technologies have the potential to have the greatest impact on the readiness of military units. Land management issues and those regarding natural and cultural resources management continue to demand the attention of Base Commanders and their staffs. Research results from this area will help to resolve legal stalemates that have occurred due to lack of scientific evidence. This evidence is required to support the position that military testing and training exercises and other practices are not negatively impacting natural and cultural resources. Successful efforts promote environmentally sound land use management and the sustainability of testing and training ranges. Accordingly, as research efforts mature to demonstration, investments in Conservation efforts are anticipated to increase.

## Scientific Advisory Board

**FY 1999 Themes- Quality research and leveraged support.**

The SERDP Scientific Advisory Board (SAB) reviewed each new start effort and every continuing project that requested FY 2000 funds exceeding $900,000. Each project was reviewed for technical quality and fiscal responsibility, and confirmed that multiple projects responding to the same or a similar requirement were complementary in approach and well coordinated. The Board paid particular attention to ensure that the project progressed and the user became increasingly involved in planning for project transition into the field.

In addition to project review, the SAB took a proactive stance in suggesting areas that are ripe for technical advancement. During this year, the SAB members once again assisted in the planning of a SERDP research opportunity workshop. The focus of this year's workshop was Air Quality Compliance. Working with the American Academy of Environmental Engineers, several members paved the way for a team of over 60 air quality specialists to investigate research opportunities to reduce/control air emissions from diesel and turbine engines, and ordnance.

At the September 1999 Council meeting, Dr. C. Herbert Ward, Chair of the Scientific Advisory Board remarked that proposal and project quality continue to increase. While much can be attributed to an excellent and comprehensive review process, the independent peer review component ensured technical quality. His encouragement reassured Council members that the Program is continuing to take the correct measures and is proceeding appropriately.

## Executive Director and Program Office

### *SERDP/ESTCP Co-Location*

FY 1999 found a co-location of the Environmental Security Technology Certification Program (ESTCP) within the SERDP Program Offices using the same technical managers and support staff to control technology development and facilitate technology transfer for both Programs. This co-location was a major step toward ensuring a close cooperation between research and development projects and the actual demonstration of environmental technology to the users in the field. Not only are research and demonstration projects managed more efficiently, but it also fosters a natural progression to facilitate technology transition for promising and well-managed technology initiatives.

Consolidation of the SERDP and ESTCP Program Offices has caused increased demands on the Program Managers for each of the four Thrust Areas. In past years, two Government Program Managers managed these four Thrust Areas. With the addition of ESTCP, responsibilities have increased with added emphasis on technology demonstration and transition initiatives. To ensure efficiency and accountability, the Director of ESTCP now serves as the SERDP Technical Director, and a third Program Manager was added to handle SERDP and ESTCP Pollution Prevention activities.

### *Proposal Solicitation and Selection*

The Council continues to be pleased with SERDP's ability to reach out to a broader pool of researchers through a Broad Agency Announcement. There are two solicitations annually – a "core" solicitation that has traditionally been used to develop the annual program - and beginning this year, a SEED solicitation. The SEED Program is designed to provide initial funding for high-risk, high-payoff proof-of-concept projects. Funding is limited to a maximum of $100,000 for up to one year. Successful efforts may compete for additional funds in the following years.

In 1999, when developing the FY 2000 program, 14 Statements of Need were prepared, four of which were specifically for the SEED program. Of the ten core SONs, nine were made available to the private sector in the BAA. The remaining SON addressed classified aspects of low observable materials and was offered only to Federal proposers.

The core solicitation responded with 141 preproposals being submitted from the non-Federal sector. Of the 51 full proposals that were requested, 14 were selected for funding resulting in a 27 percent selection rate. The Federal sector submitted 83 full proposals of which 6 were selected. Figure I-4 depicts the distribution of core proposals selected during the FY 2000 program development process.

| Thrust Area | No. of Statements of Need | No. of Proposals Selected | SOURCE | | | Approximate Value (Thrust Total) |
|---|---|---|---|---|---|---|
| | | | Federal | Academia | Private | |
| **Cleanup** | 3 | 8 | 1 | 4 | 3 | $ 5.6 million |
| **Compliance** | 2 | 6 | 3 | 2 | 1 | $ 5.3 million |
| **Conservation** | 3 | 6 | 2 | 4 | 0 | $ 3.8 million |
| **Pollution Prevention** | 2 | 3 | 2 | 0 | 1 | $ 4.3 million |
| Total | 10 | 23 | 8 | 10 | 5 | $19.0 million |

**Figure I-4. FY 2000 Core New Start Proposal Distribution by Thrust Area**

Later in 1999, the solicitation for FY 2000 SEED projects resulted in submission of 119 proposals: 24 percent from industry, 22 percent from academia, and 54 percent from Federal sources. Twelve projects were selected for funding. Figure I-5 depicts the distribution of all SEED proposals selected during the FY 2000 program development process.

| Thrust Area | No. of Statement s of Need | No. of Proposals Selected | SOURCE | | | Approximate Value (Thrust Total) |
|---|---|---|---|---|---|---|
| | | | Federal | Academia | Private | |
| **Cleanup** | 2 | 7 | 3 | 2 | 2 | $ 700 thousand |
| **Compliance** | 0 | 0 | 0 | 0 | 0 | $ 0 |
| **Conservation** | 1 | 3 | 1 | 2 | 0 | $ 300 thousand |
| **Pollution Prevention** | 1 | 2 | 0 | 1 | 1 | $ 200 thousand |
| Total | 4 | 12 | 4 | 5 | 3 | $1,200 thousand |

**Figure I-5. FY 2000 SEED New Start Proposal Distribution by Thrust Area**

## *Key Metrics for SERDP Success*

The following four key metrics were used to maintain Program quality and enhance the success of the Program in FY 1999:

**1. Address the highest-priority, defense mission-relevant environmental requirements with emphasis on multi-service issues.**

The Executive Director and his staff worked hand-in-hand with ODUSD(ES) to establish clear lines of communication, address effectively the Department's highest priority environmental requirements, and foster transition of technical efforts to field demonstration or implementation. Acting on the advice of the SERDP Council and the Scientific Advisory Board to embrace the widest competition in the selection of the proposals for FY 2000, the Executive Director again opened the SERDP solicitation process to the non-Federal sector. Through the use of tailored Statements of Need, the Executive Director solicited cooperatively funded and executed projects to address high-priority multi-service needs. The TTAWGs, SERDP's multi-Service, multi-agency planning and coordinating bodies, facilitated this process by communicating effectively and applying their knowledge of the needs and capabilities of the Federal R&D infrastructure.

In June of 1999, SERDP held a workshop on exploring the state-of-science, technology gaps, and opportunities for research in the area Air Quality Compliance. SERDP worked with the American Academy of Environmental Engineers to address this timely issue. Additionally, the Pollution Prevention TTAWG sponsored a workshop on Composites and one on Ceramics. From these workshops, several key Statements of Need were identified. Based upon their successful results, two workshops are planned for FY 2000 on the subjects of Environmental Life-Cycle Cost Accounting and Cultural Resources Management.

**2. Pursue/achieve universal, world-class technical excellence.**

World-class research is considered the cornerstone of SERDP projects. SERDP continued the use of an external peer review process in addition to the existing comprehensive multi-agency review procedures ensuring that technically sound proposals performed by world-class researchers are selected for funding. Technical experts representing universities, industry, and government participate in the Peer Review process. Additionally, the SAB, TTAWGs and the Program Office staff all emphasize and ensure that each research team demonstrates superior technical merit and performs according to world-class research standards.

One strategy that has paid significant dividends to the Program is the use of Technical Advisory Committees (TAC) to monitor progress of large umbrella-type projects and help steer the research team to better focus their research. TACs ensure that the ongoing research is consistent with the original plan and that it is still relevant; they recommend small adjustments to the plan to accommodate recent changes to DoD's needs; and they ensure the research team retains its world-class quality as the project proceeds through its plan.

**3. Emphasize and promote technology transfer.**

Transfer of technology, from research to the DoD environmental user community, is a key objective of SERDP. This overall program objective is achieved by supporting applied research and technology demonstrations that respond directly to high-priority, DoD mission-related, environmental needs. With FY 1999 marking its eighth year of technology development, SERDP is aggressively pursuing technology transfer mechanisms. The co-location of ESTCP with SERDP promises to facilitate project transitions, both between Programs and into other Agencies' certification programs as well. Many of the projects initiated in the earlier years have been, or are being completed and are now ready for implementation or transition to the next step of development.

Additionally, increased focus on technology transfer has been placed on the Principal Investigators (PI) of all SERDP projects at both briefings to the SAB as well as at the In-Progress Reviews (IPR). At these IPRs, PIs are required to demonstrate their interaction with the user community or those who will sponsor further development. Members of the multi-agency TTAWGs, Joint Engineers Management Panel (JEMP) members, and key representatives from ODUSD(ES) were in attendance and provided various potential technology transfer opportunities to the PIs.

In November 1999, the annual Partners in Environmental Technology Technical Symposium and Workshop sponsored by SERDP once again succeeded in providing an excellent technology transfer and networking forum for researchers, scientists, and engineers from both the Federal laboratory system and the non-Federal sector alike. Our venue focused on Sustainable Development and encouraged meeting today's needs while preserving our future. This event brought more than 575 technology developers and implementers together, as well representatives from the policy, programmatic, regulatory, academic, and industrial sectors - its largest attendance to date. This conference, which has received numerous accolades, will continue to be enhanced to serve as a significant technical, educational and technology transfer event.

**4. Ensure sound fiscal management.**

Timely and complete financial reporting is one of the principal keys to SERDP's success. The SERDP Executive Director has continued to ensure that the Program complies with the DoD fiscal guidance. Effective controls include periodic fiscal review of projects, implementing aggressive corrective actions to promote effective use of scarce R&D resources, and implementation of various information management/monitoring tools which fully utilize state-of-the-art Internet capabilities.

## *Plans for FY 2000*

Plans for the SERDP Program in FY 2000 include the following:

- Continue to provide world-class research in response to the Department's highest priority environmental needs while serving in its role as the DoD Corporate Environmental R&D program.
- Continue non-Federal sector direct participation via Broad Agency Announcements for the solicitation of FY 2001 proposals.
- Continue external peer review for evaluating FY 2001 proposals received from both the Federal and non-Federal sectors.
- Continue the use of Technical Advisory Committees to assist the research teams of large umbrella projects to focus and integrate their efforts.
- Continue to bridge technology from Science and Technology through to Dem/Val by conducting annual In-Progress Reviews in conjunction with ESTCP.
- At the recommendation of the SERDP Scientific Advisory Board, conduct a Workshop in 1999 to address research needs for environmental life-cycle cost accounting methods. Conduct a Cultural Resource Management workshop.
- Conduct the annual Technical Symposium and Workshop, focusing on technology transfer and increasing awareness of SERDP and SERDP-related efforts within the DoD user community.

**In FY00, SERDP will continue to exercise the four SERDP Key Metrics to Success.**

# II. SIGNIFICANT ACCOMPLISHMENTS

## Introduction

Since its inception in 1991, SERDP has responded to the Department of Defense's (DoD) highest priority requirements by supporting just under 300 environmental science and technology projects. These projects have enabled DoD installations to meet their environmental responsibilities using cost-effective and innovative methods. During FY 1999, SERDP continued to play a critical role in the development of science and technology that supports the DoD's environmental security goals. Several of SERDP's most significant accomplishments during the past year are described in this section. While these projects represent only a small selection of the many innovative and groundbreaking projects supported by SERDP, they show the breadth and depth of the Program and highlight the most significant accomplishments of FY 1999. Moreover, these accomplishments demonstrate the potential cost savings while simultaneously maintaining mission readiness when new technologies become fully implemented. Appendices A through D provide detailed information on each SERDP project for FY 1999.

## Cleanup Accomplishments

### UXO

Unexploded ordnance (UXO) presents a challenge to active military installations seeking to manage and clean up their test and training ranges, to sites designated for base realignment and closure (BRAC), and to formerly used defense sites (FUDS). In the United States alone, current estimates indicate that more than 900 sites (11 million acres) with varying terrain, foliation, and topography (including 50 underwater sites) are potentially contaminated with UXO. Using current technologies, the cost of identifying and disposing of UXO in the U.S. is estimated as high as $500 billion. New technologies capable of detecting UXO with high detection rates and low false alarm rates are required to drastically reduce the cost of site characterization and cleanup. Figure II-1 depicts typical UXO and clutter that researchers encounter in the field. SERDP is investing in UXO technology development through 13 projects, including five FY00 New Start SEED projects and two projects completed in FY99.

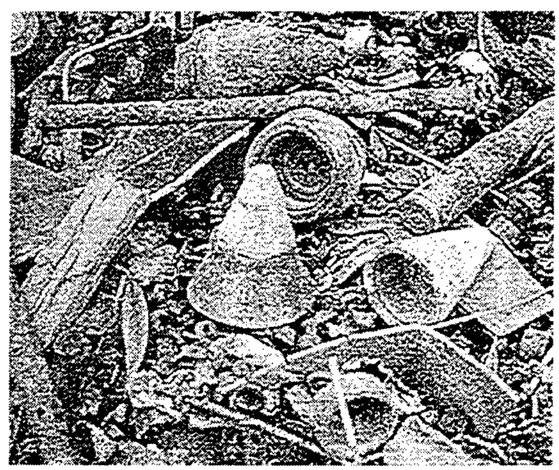


**Figure II-1. An Example of the UXO and Clutter that is the Focus of SERDP Cleanup Efforts**

During FY99, improved coordination and cooperation between SERDP-funded UXO related efforts continued to be a high priority, as did coordination with other ongoing UXO-related research. To facilitate this coordination, SERDP and the Environmental Security Technology Certification Program (ESTCP) co-sponsored a UXO Technology Exchange Meeting (TEM) in January 1999 that included both SERDP- and ESTCP-funded UXO efforts. Representatives from other UXO-related organizations outside of SERDP and ESTCP were invited and participated as well. These participants represented universities, private sector companies, other Federal oversight agencies [Joint Unexploded Ordnance Coordination Office (JUXOCO)], other Federal funding sources [Defense Advanced Research Projects Agency (DARPA)], and managers of UXO test sites. Those that participated welcomed and utilized the opportunity to exchange concerns and progress being made in the UXO detection/discrimination arena. An example of the benefits of this increased level of communication is the increased coordination within an FY99 New Start effort in which investigators performing data fusion and interpretation have utilized numerous existing data sets generated under other /SERDP-funded UXO projects.

The project team from Duke University performing **Statistical Signal Processing with Physics-Based Models: Multi-Sensor UXO Detection and Identification (CU-1123)** has undertaken rigorous phenomenological modeling of electromagnetic wave propagation and scattering at ultra-wideband radar and electromagnetic induction (EMI) frequencies (20-1200 MHz and 0.1-100 KHz, respectively). Researchers are seeking to delineate those phenomenological features that most discriminate UXO targets from anthropic clutter. The research team has collaborated with current SERDP-sponsored organizations Army Research Laboratory (ARL), Naval Research Laboratory (NRL), and a private sector research firm (currently performing accoustic-based UXO research described here). For each sensor modality, the researchers have parsed the modeled signatures into their fundamental constituents, defining a "wave-based dictionary" or "codebook" to be exploited in signal processing.

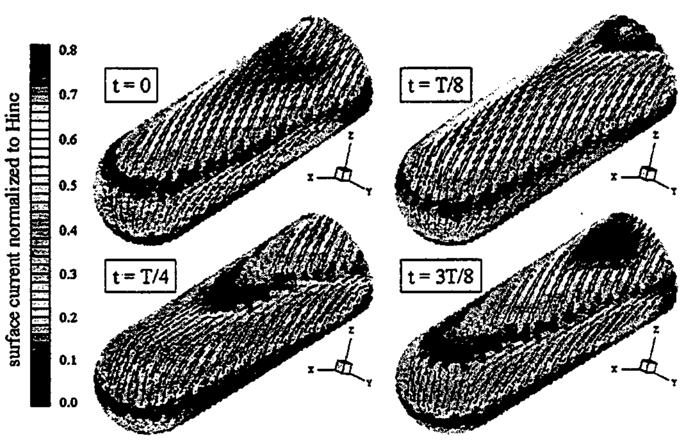



**Figure II-2. An Example of the Algorithm Results from CU-1123**

In FY99, work focused on the development of optimal signal processing algorithms that rigorously incorporate the underlying physics characteristic of the sensor and the anticipated UXO target in order to address the false alarm issue. The team has developed several phenomenological models and used them to predict the EMI and magnetometer responses and evaluate the advantages and limitations of each. The team also has successfully explored a variety of signal processing techniques incorporating these physics-based models that have been applied to the data measured during field demonstrations, as well as comparing and contrasting the performance of the various algorithms, including tradeoffs such as training requirements.

With regard to synthetic aperture radar (SAR)-based systems, the team developed a multi-level fast-multipole algorithm (MLFMA) for modeling radar scattering from electrically large targets arbitrarily buried in a half space. Simulation results are depicted in Figure II-2. This model results in considerable computational savings, and the results of the MLFMA have been favorably compared with data measured by the Army Research Laboratory. The model now is being used in conjunction with the SAR signal processing and will be compared to data collected in the future. In addition, work continues to evaluate any limitations of the model, particularly with respect to the computation requirements for large ordnance. Efforts will continue in FY00 to pursue improved target detection and identification for UXO discrimination, specifically how both the sampling strategy (i.e., uniform, geometric, logarithmic sampling in time and/or space) and the number of poles being estimated affects pole estimation performance.

SERDP continued funding FY98 UXO efforts to assess the ability of non-traditional sensors to detect and discriminate UXO from background clutter. One effort, **Innovative Seismic System for Buried UXO Detection & Classification (CU-1091)**, is exploring the use of seismic technologies that provide a means of remote sensing the mechanical properties and structural vibrations of objects below the surface of the ground. A seismic sensor has the potential to add a powerful tool to discriminate ordnance from clutter and reduce remediation costs significantly. Research has been conducted to develop a broadband high frequency seismic system to discriminate UXO from other objects buried in soil. During FY99, the research team led by BBN Systems and Technologies completed the development of a 2½-D elastic Finite Element Modeling capability for calculating target response of axisymetric objects. This new tool has been used to model mechanically realistic ordnance items to examine them for characteristic resonances and estimate target strength. The researchers have performed finite element calculations for the seismic response of a 155 mm artillery shell, and these resonances were confirmed by measuring the vibration of a 155 mm shell buried in the soil.

FY99 efforts also included performance of seismic field tests in order to characterize seismic propagation. Through analysis of field data, the research team has developed models of reverberation that have been used in the system simulation software to design a two-dimensional, multi-element array of receivers for detecting the seismic response of UXO remotely. As depicted in Figure II-3, the fixed geometry array of 60 acoustic sensors has been engineered to allow rapid and accurate placement in the field. In addition, advances have been made in the redesign of seismic sources and receivers during FY99 to significantly extend their high frequency coupling. An example of this redesigned accelerometer probe receiver that will be used in conjunction with the array is depicted in Figure II-4.

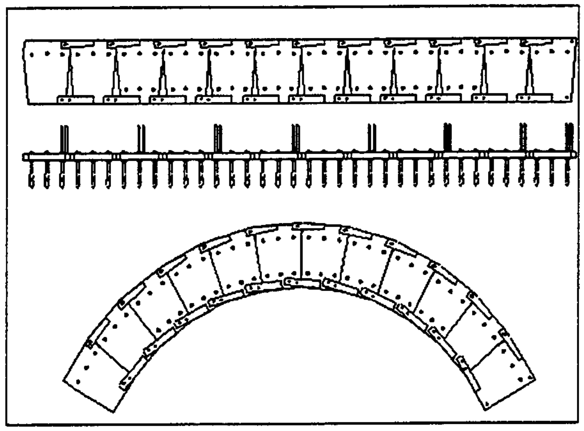


**Figure II-3. The Acoustic Sensor Array Engineered to Allow Rapid and Accurate Placement in the Field**

## Bioremediation

Remediation of DoD sites using existing technologies is problematic from an economic, technical, and political point of view. The projected costs associated with site restoration are estimated to be on the order of $30 billion dollars. Current technologies are frequently invasive, requiring the movement of large volumes of soil and/or water, and are also energy and materials intensive. In addition, many of these technologies simply transfer the contaminant from one media to another, where it often still requires treatment. The **Federal Integrated Biotreatment Research Consortium (FIBRC): Flask to Field Initiative (CU-720)** is a large, multifaceted project to develop field-ready biotechnologies in each of the following focus areas: 1) Explosives; 2) Chlorinated Solvents; 3) Polychlorinated Biphenyls (PCB); and, 4) Polycyclic Aromatic Hydrocarbons (PAH). The target is to develop inexpensive, field-ready biotreatment processes. Following is a description of FY99 accomplishments under this umbrella project being coördinated by the U.S. Army Corps of Engineers, Engineer Research and Development Center–Environmental Laboratory.

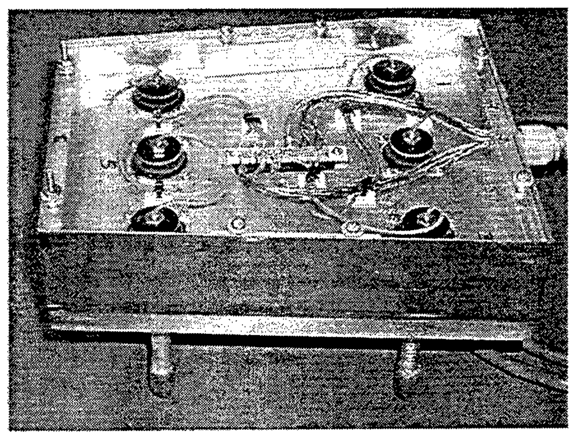


**Figure II-4. The Redesigned Accelerometer Probe Receiver**

### *Bioremediation of Explosives*

Explosives contamination represents one of the most prevalent types of organic contamination within the DoD. Therefore, a variety of innovative and promising biotreatment techniques with potential high payoff have been investigated for remediating soil and groundwater. During FY99, successful field work by SERDP-funded researchers focused on the degradation of dinitrotoluene (DNT), a major contaminant at the Badger Army Ammunition Plant (BAAP) Propellant Burning Ground (PBG). Until very recently, no technology existed for efficient biodegradation of DNT; however, discovery of bacteria that mineralize both isomers of DNT has enabled the development of an effective bioremediation strategy. Studies were conducted with DNT-contaminated soils from BAAP to provide the basis for full-scale implementation.

Studies to simulate in-situ remediation were conducted in glass columns filled with soil from the PBG. The

results indicate the presence of an indigenous bacterial population capable of completely degrading 2,4-DNT in PBG soil. Such a population can be exploited in an engineered in-situ bioremediation strategy for the contaminated soil. Further studies are under way to determine the principal parameters to control for optimal DNT degradation.

## Bioremediation of Chlorinated Solvents

An effort funded under the FIBRC is attempting to demonstrate the feasibility of a treatment train approach to remediating the source zone of a dense non-aqueous phase liquid (DNAPL) contaminated aquifer. The Solvent Extraction Residual Bioremediation (SERB) process pursues enhanced removal of the source contaminants with cosolvent extraction (see Figure II-5) and subsequent biodegradation of dissolved contaminants (see Figure II-6). If these technologies can be coupled successfully, the SERB could greatly reduce cleanup costs.

The alcohol flushing pilot test was performed successfully in August 1998. This pilot-scale test has demonstrated that the technology is very effective at solubilizing contaminants, such as perchloroethylene (PCE), making them susceptible to treatment by extraction and bioremediation. Analysis of the extraction well data shows that a significant mass of PCE (> 40 liters) was removed during the cosolvent extraction process. Dissolved phase PCE concentrations in the source zone area decreased immediately following the cosolvent flush and have rebounded, as expected, over the past year, while ethanol concentrations have remained at 10,000 mg/L. Groundwater monitoring has indicated that conditions conducive to reductive dechlorination have been created in this zone. Indications of reductive dechlorination of PCE are 1) formation of the daughter products, trichloroethylene (TCE), cis-dichloroethylene (DCE), vinyl chloride (VC), and ethene (ETH), 2) an increase in chloride, hydrogen, and methane concentrations, and 3) a decrease in sulfate concentrations. The SERB process has been successful at the pilot test site in removing a significant mass of PCE and enhancing the reductive dechlorination of the remaining dissolved phase contaminant. Laboratory microcosm studies were conducted in FY99 to validate the field test results. These studies indicate that the site materials contain indigenous organisms that dechlorinate PCE. Daughter products, TCE and cis-DCE, were formed in microcosms that contained ethanol as the electron donor. Molecular probing techniques have detected an organism that may be capable of complete dechlorination of PCE to ethene.

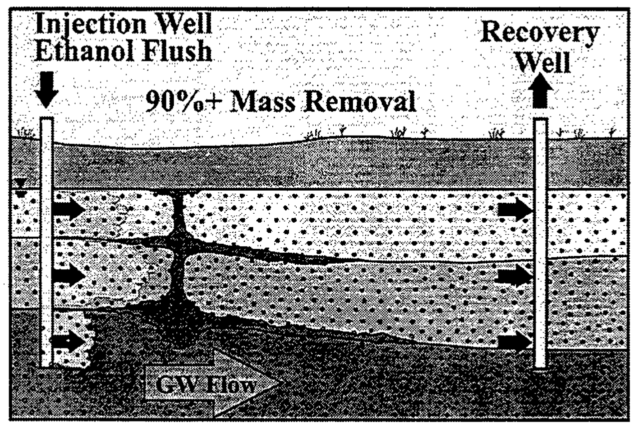



**Figure II-5. The Cosolvent Flush Portion of the SERB Process Will Remove 90%+ of the Mass of Contamination**

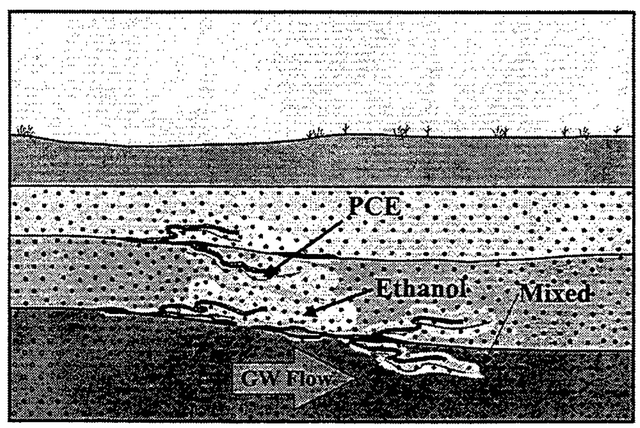



**Figure II-6. Following Cosolvent Flush, the Residual Contamination Conditions Will Support Reductive Dechlorination**

## *Bioremediation of PCBs*

As part of the FIBRC project, this effort addresses key barriers to bioremediating PCBs, which are (1) developing microorganisms that will grow on the major congeners produced by anaerobic dechlorination of PCBs, (2) improving bioavailability of PCBs through use of surfactants, and (3) optimizing field delivery of anaerobic/aerobic PCB bioremediation technologies. During FY99 these researchers continued to pursue the genetic engineering of organisms capable of growing on PCB contamination. Significant progress was made in determining the survivability of the bacteria in actual PCB contaminated soils. Microcosm experiments conducted in FY99 with control soil from the Picatinny Arsenal site indicated good survivability (over 1 month incubation period), genetic stability, and degradative activity. To overcome the problem associated with the low solubility of PCBs, work in FY99 also focused on evaluating surfactants that potentially could enhance PCB bioavailability and biodegradation. Successful PCB-surfactant solubilization experiments were conducted in FY99 with surfactants that increase PCB solubility without inhibiting bacterial activity.

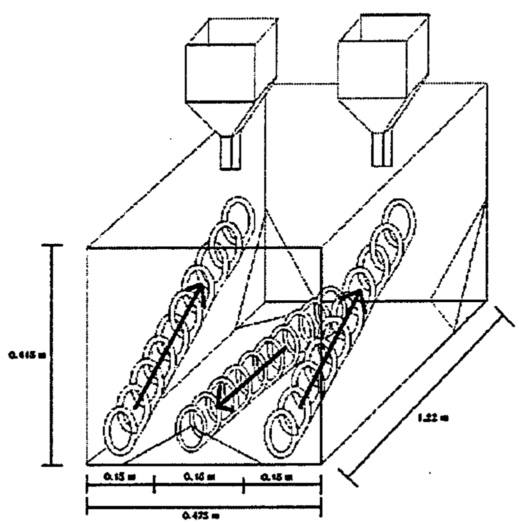


**Figure II-7. Schematic Diagram of a Bioreactor Equipped with Shaftless Screw Conveyers for PCB Remediation**

Work has continued in FY99 to move toward a field-scale experiment involving the augmentation of PCB contaminated soils with these engineered bacteria, specifically on development of a bioreactor. Since the material will be excavated and possesses a rather low solids loading, it was decided that an ex-situ bioreactor would be used to treat the PCB-contaminated material. The use of an ex-situ bioreactor also allows for greater control over system parameters and for the containment of genetically engineered microorganisms (GEM). The bioreactor system currently being designed and tested is based on the premise that low energy or gentle mixing will be sufficient to enhance mass transfer and is preferred for microorganism growth survival. In addition, a relatively low water content or high solids loading (~50-60% wt) will be employed compared to typical bioslurry reactors, which operate at 5 percent to 20 percent solids (wt). In order to move and mix the contaminated material at such high solid contents, shaftless screws will be used in the reactor configuration. As depicted in Figure II-7, a 1/5-scale bioreactor has been constructed. The reactor currently is undergoing testing to ensure that the shaftless screws can move the contaminated material, study the effect of water content on conveyer performance, and quantify mixing of solution and solids within the matrix.

## Environmentally Acceptable Endpoints Initiative

Considerable research has been under way in recent years to identify Environmentally Acceptable Endpoints (EAE) in soil, to develop protocols that can be used to determine EAEs, and to make site-specific cleanup decisions based upon EAE data. EAEs for soil are most commonly defined as concentrations of chemicals or other measures of contamination (e.g., biological response or leachability) that are judged acceptable by a regulatory agency or an appropriate entity, either a'priori - as in a standard or a guideline - or following an analysis of site-specific information.

The EAE-related SERDP-funded effort, **Assessment & Prediction of Biostabilization of Polycyclic Aromatic Hydrocarbons (PAH) in Sediment (CU-1095)**, made significant progress in FY99 and was awarded SERDP's Cleanup "Project of the Year" for FY99 at the annual *Partners in Environmental Technology* Technical Symposium & Workshop held November 30 - December 2, 1999. Since its initiation

as an FY98 New Start, this project has investigated *biostabilization* – a newly-developed concept whereby accessible pollutants are biodegraded in a soil or sediment matrix, leaving a bound residue that is much more biologically unavailable and immobile.

This research project has sought to identify those factors affecting biostabilization of PAHs on sediments and to develop the technical basis for enhancing natural recovery processes that occur in-situ during biotreatment of sediments contaminated with PAHs. In FY99, the research teams from the U.S. Army Corps of Engineers, Engineer Research and Development Center–Environmental Laboratory, Carnegie - Mellon University, and Stanford University used a suite of microscale spectroscopic and spectrometric techniques to investigate biostabilization. As depicted in Figure II-8, the black particles show high PAH mass signal from laser desorption-laser ionization mass spectrometry, high organic carbon identified by the strong IR signal near 2900 wavenumbers, and high elemental carbon content. The silica particles show a very low PAH signal, very low IR absorbance near 2900 wavenumbers, and high silicon and oxygen content. This investigation has revealed that for harbor sediments from two sources, PAHs reside primarily on black coal-derived particles. This is the first direct evidence at the microscale of a physically distinct class of particles that sequester most of the PAHs.

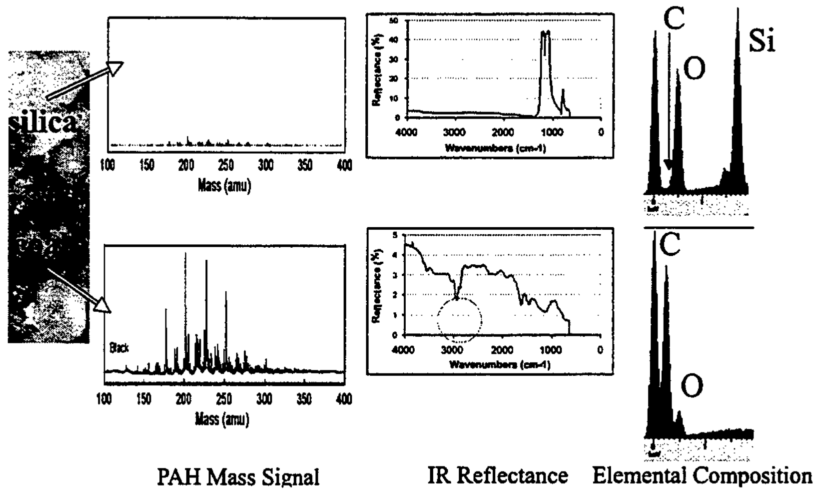



**Figure II-8. Direct Evidence at the Microscale of a Physically Distinct Class of Particles Sequestering Most of the PAHs**

This research will continue to expand on these EAE-related results in FY00 providing 1) microscale analytical tools to evaluate causes of sequestration and low bioavailability; 2) insights regarding whether PAHs on clays/silt may be biotreatable, leaving "biostabilized" PAHs on coal-derived particles; and, 3) implications for development of site-specific sediment quality guidelines.

## The NETTS Program

The Tri-Service and the Environmental Protection Agency (EPA) test locations of the SERDP National Environmental Technology Test Site (NETTS) program comprise a network of well-characterized demonstration sites at DoD installations. The goal of this SERDP-funded program is to provide accessible, well-supported field locations for project proof-of-principle tests, applied research, and comparative demonstrations, as well as to facilitate transfer of innovative environmental technologies from research to full-scale use. Established in FY93, the SERDP NETTSs are available to DoD, Department of Energy (DOE), and EPA users, as well as other agencies and the private sector. The following are the Test Locations that constitute the NETTS Program: 1) Naval Construction Battalion Center (CBC) Port Hueneme in California; 2) McClellan Ar Force Base (AFB) also in California; 3) Dover AFB in Delaware; and 4) Former Wurtsmith AFB in Michigan. Although many demonstrations were hosted at the NETTS Locations during the last fiscal year, two key successes related to demonstrations at the SERDP-funded NETTS Locations in FY99 are detailed below.

### *Passive Diffusion Membrane Samplers – McClellan AFB*

In a U.S. Geological Survey (USGS) project sponsored by the Air Force Center for Environmental Excellence, passive diffusion membrane samplers have been demonstrated at the McClellan AFB NETTS

location to collect groundwater for volatile organic compound (VOC) analysis. Sampling was conducted concurrently with the McClellan AFB quarterly groundwater sampling event to allow direct comparison of the new technology with the currently used purge-and-sample methods. As depicted in Figure II-9, the diffusion samplers are constructed from 18-inch sections of low-density polyethylene tubing and are filled with deionized water before insertion into a monitoring well. The polyethylene membrane allows VOCs in the groundwater to diffuse into the deionized water inside the membrane. Purging of the monitoring wells is not necessary before use. Chemical equilibrium between the water in the well and the sampler water typically occurs within two to three days, resulting in a sample that is representative of VOC concentrations in the groundwater.

**Figure II-9. The Diffusion Sampler Demonstrated at the McClellan AFB NETTS Location**

Samplers (207 in total) were installed along the long-screened sections of 30 groundwater monitoring wells in May 1999 and were left in place for 2-3 weeks before retrieval for VOC measurement. Preliminary results have shown that diffusion samplers provided accurate VOC analyses representative of aquifer conditions at McClellan AFB. Statistically significant correlations with conventional well-sampling methods were obtained under several hydrogeological conditions.

The diffusion sampler methodology was designed as an inexpensive approach to minimizing the labor and wastewater disposal costs of groundwater sampling, while providing samples of equal or greater quality than conventional methods. The potential cost savings for long-term monitoring are significant. Initial cost/performance analysis shows that these cost savings are expected to be greater than $200/sample as compared to conventional purge and sample techniques. In addition, the results of this field investigation will be used to evaluate the suitability of the diffusion samplers to meet Federal and California State long-term monitoring criteria.

## *Enhanced DNAPL Source Removal – Dover AFB*

At the Dover AFB NETTS location, the EPA's National Risk Management Research Laboratory and the Air Force Research Laboratory are conducting a series of enhanced source removal demonstrations focusing on the clean up of dense non-aqueous phase liquids (DNAPL) contamination in soil and groundwater under the SERDP-funded project, **Aquifer Restoration by Enhanced Source Removal (CU-368).** DNAPLs, specifically chlorinated solvents, tend to remain in the soil regardless of the amount of groundwater that is pumped out of the zone because of their very low solubility in water. Thus they are not easily removed by conventional pump-and-treat methods.

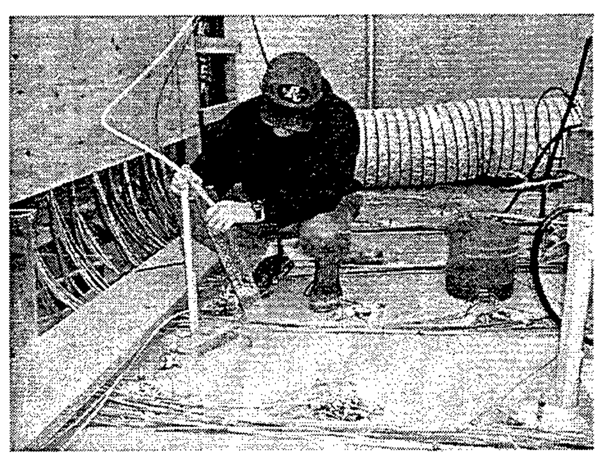


**Figure II-10. The Contained Release Test Cell Allows Direct Injection of DNAPL to the Subsurface During Demonstration at the Dover AFB NETTS Location**

The first of these field tests was to evaluate the efficiency of in-situ ethanol flushing to solubilize and extract DNAPLs. In February 1999, University of

Florida researchers conducted a cosolvent flood to solubilize and extract perchloroethylene (PCE) from a 10 foot by 16 foot hydraulically contained release cell made out of interlocking steel sheet piling that extends from the ground surface to a depth of 50 feet. At the start of the demonstration, 92 liters of PCE were released into the saturated zone of the test cell, as depicted in Figure II-10. The goal of the PCE release was to create a contaminated zone between the injection points (35 ft bgs) and the underlying clay interface (40 ft bgs). The demonstration consisted of flushing the test cell with a remedial injection fluid to dissolve the PCE, followed by extraction and treatment of the fluids at the surface to recover the PCE. The injection fluid (5 percent water plus 95 percent ethanol cosolvent) was injected through six injection wells and pumped through the contaminated media before removal in two extraction wells. Flushing was conducted over a 90-day period, during which time eight pore volumes were flushed through the cell by recycling the ethanol for multiple passes. A partitioning tracer test was conducted prior to and after the flushing demonstration to determine the amount of PCE remaining within the test cell. The PCE was removed at a much greater rate than would have been possible by conventional pump-and-treat methods.

# Compliance Accomplishments

## Monitoring and Measurement

The 1990 Clean Air Act Amendments (CAAA) require facilities to monitor/measure criteria air pollutants, which include nitrogen oxides (NOx) and particulate matter (PM), as well as hazardous air pollutants (HAP), which include 189 individual toxic compounds. Many of these pollutants are emitted during DoD and DOE operations and need to be monitored and characterized in order for these facilities to maintain their permits. To reduce the costs associated with chemical analyses of these air emissions, DoD is seeking alternatives to traditional sampling and time-consuming analytical methods used to meet the current compliance monitoring requirements. Specifically, the current National Ambient Air Quality Standards (NAAQS) for one of the criteria air pollutants, PM, is under review and will probably result in additional and more stringent future standards for monitoring PM less than 2.5 microns in size ($PM_{2.5}$).

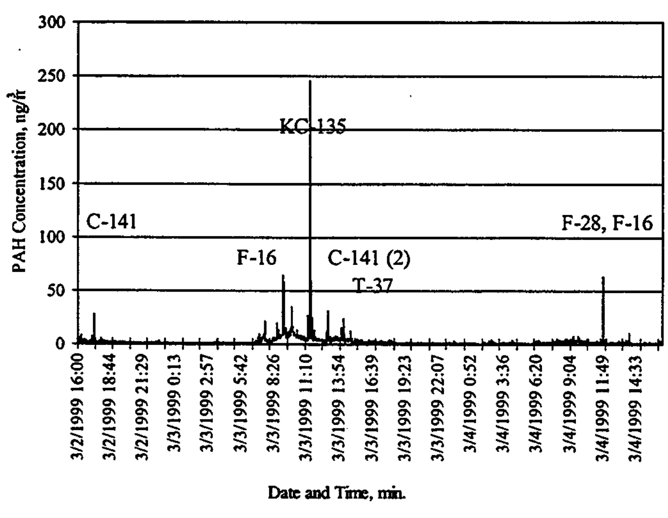



**Figure II-11. PAH Concentrations as a Function of Aircraft Activity Measured on an Air Force Base Runway**

The DoD needs to characterize both the particle size and the chemical composition from several emissions sources, such as turbines, boilers, and vehicles, which would likely be impacted by the NAAQS. SERDP currently is funding a project to provide DoD the capability to monitor and characterize $PM_{2.5}$. Through the project **Characterization of Particulate Emission: Size Characterization and Chemical Speciation (CP-1106)**, investigators at the University of Utah are developing innovative sampling and analytical techniques to monitor and characterize PM in the field. The techniques evaluated in FY99 included the integration of a portable dilution sampler; an Aerosol Time-of-Flight Mass Spectrometer (ATOFMS) for analysis of inorganic and organic compounds in PM; a photoelectric detector (PED) for rapid, composite measurement of PAHs that are prevalent in PM; and micro-orifice impactors to obtain size-segregated particles for chemical analysis. The ATOFMS was used to analyze organic & inorganic single particles in diesel & spark ignition engine

exhausts. Preliminary analyses of $PM_{2.5}$ diesel exhaust indicate that it is composed of 64 percent organic carbon and 32 percent elemental carbon. The capabilities of the PED technology were tested at an Air Force base runway to measure total PAH concentrations as a function of aircraft activity (Figure II-11). These analytical techniques will provide DoD with a previously unavailable capability to determine the composition and size distribution of ultrafine PM. Once the instruments are calibrated on major classes of DoD-relevant sources, a detailed field study will be conducted that will provide a wide representation of typical DoD emissions sources.

## "End-of-Pipe" Reduction

DoD has a growing need to control the emission of criteria air pollutants, such as NOx and VOCs, as well as HAPs at its installations. These emissions frequently are episodic and variable with respect to the types of constituents and their concentrations. Existing control technologies have significant drawbacks, including not meeting the current and expected restrictions on emissions of NOx/VOCs/HAPs. Without new technologies, the curtailment of missions, closing of facilities, and assessment of fines are real possibilities.

Non-thermal plasma (NTP) technologies show promise for addressing current and future needs to reduce or remove NOx. The **Plasma Assisted Catalytic Control of NOx (CP-1077)** project is further developing and optimizing selective catalytic reduction (SCR) technology by using non-thermal plasma (NTP) pretreatment to assist with the destruction of nitrogen-species in gaseous emissions (Figure II-12). This research is being conducted by the Air Force Research Laboratory at Tyndall AFB and Lawrence Livermore National Laboratory at Livermore, CA. In the SCR process, the destruction of partially oxidized nitrogen-based contaminants found in combustion-exhaust emissions proceeds by catalytic oxidation of nitrogen-species to nitrogen dioxide ($NO_2$). $NO_2$ subsequently is reduced to nitrogen ($N_2$) by a hydrocarbon (HC) in the presence of another catalyst. By pretreating the inflow of exhaust with an NTP, additional ions, electrons, and radical species are generated which aid the desired conversions.

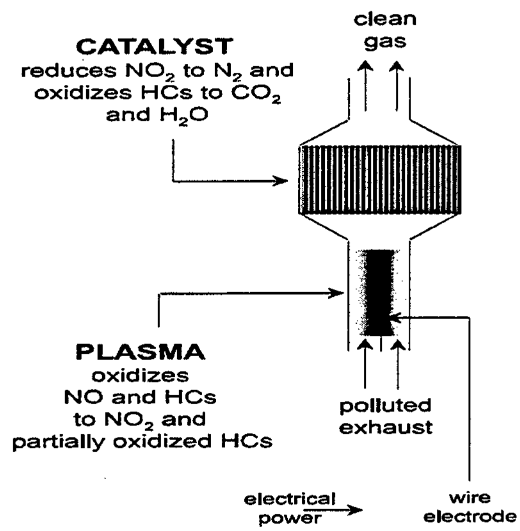



**Figure II-12. Schematic of Non-Thermal Plasma-Assisted SCR Emissions Control Process**

In FY99, a full-scale NOx control system was completed and successfully operated to treat the full exhaust flow from a Cummins 100-kW generator set. This unit is typical of aircraft ground support equipment and representative of medium-sized diesel engines used to power mobile and stationary heavy equipment. In an analysis of NOx conversions, the NTP-SCR enhanced the conversion of NOx over that of conventional wet-scrubber technology. Preparations have been completed for testing a corona radical shower NTP in the exhaust stream of a cruise missile test cell in FY 2000. In addition, a two-dimensional computational-fluid dynamics and chemical kinetics/reaction model of the silent discharge NTP reactor was completed allowing the prediction of the reactor's detailed kinetics and chemical transport.

Other sources of air emissions, including those from the application or removal of coatings, results in releases of VOC contaminants that must be treated to maintain compliance with the CAAA of 1990. Available VOC emissions control technologies are costly at the high volumetric flow rates and low contaminant concentrations associated with ventilation of aircraft hangars. The researchers from the University of Texas at Austin working on the **Biofiltration VOC Control Technology for Aircraft Painting Facilities (CP-1104)** project are investigating an innovative, high-flow-rate biofiltration method which has the added advantages of improved safety and no secondary waste streams. Currently, biofilters

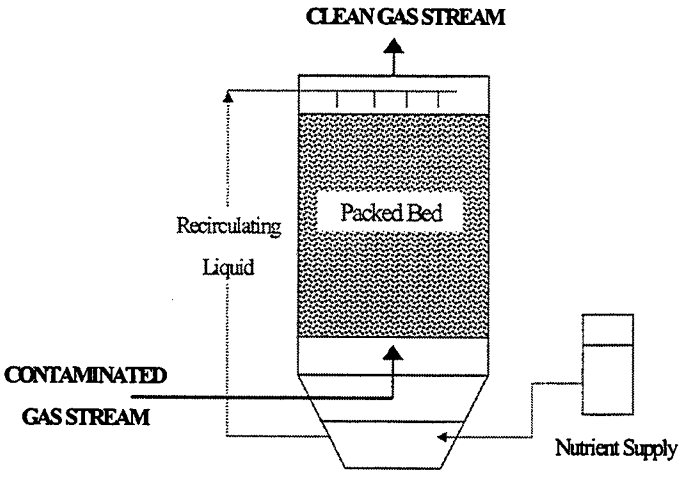



**Figure II-13. Schematic Diagram of Biofilter to Treat VOCs from Aircraft Painting Booths**

experience problems such as long biomass acclimation times, slow response to load changes, and biomass clogging. The novel biofilter design developed under SERDP in FY99 incorporates several innovative features such as recirculation inoculation during start-up, a slip-stream feed system to maintain biofilter viability during low loading or shutdown of painting operation, periodic changes in feed direction through the filter, and a nutrient aerosol delivery system (Figure II-13). The researchers have constructed two stainless-steel laboratory-scale bioreactors that currently are treating toluene-contaminated air. To evaluate biofilter operation, a dye method was developed to be able to 1) determine the distribution of active biomass throughout the biofilter and 2) distinguish between active and inactive biomass. Bacterial cultures have been developed that are capable of degrading the major contaminants found in paint spray emissions, including toluene, ethyl acetate, and methyl ethyl ketone (MEK) individually but not in combination. The use of fungal cultures as contaminant degrading agents and various support media to reduce clogging also are being evaluated.

DoD and DOE also are in need of new, cost-effective control technologies to comply with the proposed, more stringent EPA standards for $PM_{2.5}$ from sources such as Jet Engine Test Cells (JETC), diesel engines, generators, incinerators, and steam boilers. The investigators from CeraMem Corporation working on the **Development of a Catalyzed Ceramic Filter for Combined $PM_{2.5}$ Removal and VOC and CO Oxidation (CP-1120)** project will generate a highly-compact, ceramic membrane-coated, silicon carbide (SiC) monolith filter (Figure II-14) which can be coated with non-selective catalysts to remove PM while simultaneously oxidizing vapor-phase VOCs and carbon monoxide (CO). The oxidation catalysts also can result in "passive" regeneration of PM to allow extended continuous operation. The ceramic filter technology will yield a Best Available Control Technology (BACT) for specific operational niches such as 1) confined spaces, 2) high temperature demands, and 3) simultaneous removal of PM, VOCs, and CO, with the potential for additional downstream NOx destruction. Passively-regenerated filters are being prepared and test equipment has been designed, reviewed for safety, and assembled. In FY99, membranes of different configurations were developed to minimize pressure drop with high particulate removal efficiency. Initial testing with small test filters have indicated that particulate removal efficiencies are well in excess of 95 percent while pressure drops are below the project target of 15 inches of water at 10 ft/min face velocity.

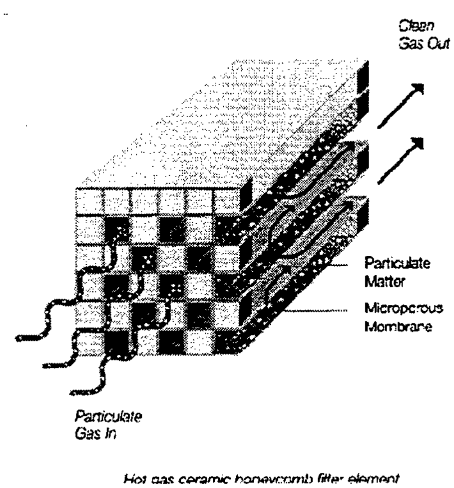
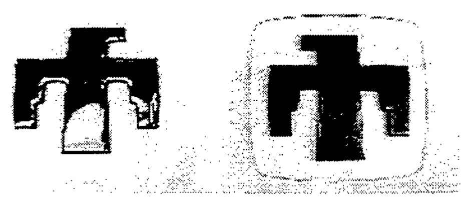



**Figure II-14. Ceramic-Membrane-Coated Filter Removes $PM_{2.5}$, VOCs, and CO**

## Treatment of Energetic Materials Waste

The DoD faces many environmental and legal issues associated with the demilitarization of obsolete, excess, and off-spec energetic materials and assembled munitions. The DoD stockpile of energetic materials that needs to be destroyed is approximately 700,000 tons, and this amount increases at a rate of about 60,000 tons per year. The DOE also has a significant amount of weapons components that needs to be destroyed. To ensure compliance with increasingly stringent regulations, DoD and DOE require alternatives to the open burning/open detonation (OB/OD) of energetic materials and munitions.



**Epoxy RDX/Amine by-product** **Epoxy TNT/Amine by-product**

**Figure II-15. Two Epoxy Products (the Sandia National Lab Logo) Derived from Non-Detonative Conversion of RDX (Left) and TNT (Right)**

Through the SERDP project **Hypergolic Non-Detonative Neutralization of Energetics (CP-1079)**, an innovative alternative to OB/OD has been identified that will provide for the safe destruction of energetic materials. Researchers from Sandia National Laboratories working on this project have identified a chemical process to react energetic materials with hypergolic chemicals, specifically organic amines, which neutralize the energetic materials. The organic amines react with TNT, RDX, and Comp B at low temperatures leading to a safe breakdown of the explosive material without detonation. These reactions produce gaseous and liquid by-products. The gases were collected and analyzed by gas chromatography and infrared analyses and were found to consist of nitrous oxide, nitrogen, water, and carbon dioxide. The liquid by-products for both RDX and TNT were found to be effective curing agents for conventional epoxy resins which can be used for commercial processes. Structural tests indicate that the mechanical properties of the polymers produced with these curing agents are comparable to control samples of epoxy formed from conventional resins and curing agents. The epoxy polymers produced with the curing agents developed in this project were subjected to several safety and structural tests and found to be safe. Some additional tests are under way to verify their safety and resistance to leaching toxic of compounds. The results of this research indicate that a viable alternative to OB/OD exists for the destruction of energetic materials such as TNT, RDX, and Comp B. The method developed will meet DoD and DOE requirements for high throughput, cost-effectiveness, safety, and zero discharge of toxic chemicals to the environment with an added benefit of the production of safe and environmentally benign by-products such as the epoxy polymers shown in Figure II-15.

# Conservation Accomplishments

## Threatened and Endangered Species

DoD lands are the home for a variety of threatened and endangered species (TES). These lands also serve as military training areas with numerous types of imposed conditions that may have adverse effects on these and other species. The Army alone has identified more than 150 TES on its lands, and this number is projected to increase. The U.S. Fish and Wildlife Service has indicated that an average of 100 species per year are examined and have the potential to be Federally listed. One of the imposed conditions on these military installations is the release of smokes and obscurants, especially fog oil, during training and testing exercises, including National Guard training. Until recently, very little was known about the true effects of fog oil on TES. Without a quantitative study, it might become necessary for the military to reduce its use of smokes, obscurants, and riot-control agents during testing and training activities. Additionally, the potential exists for lengthy and costly litigation resulting in criminal and civil penalties.

**Figure II-16. Fog-Oil Smoke Generated at Ft. McClellan, AL**

As part of SERDP's **Threatened, Endangered, and Sensitive Resources (CS-507)** project, the U.S. Army Corps of Engineers Engineer Research and Development Center and DOE's Pacific Northwest National Laboratory analyzed the effects of fog oil on TES (visit http://www.cecer.army.mil and search on smokes and obscurants). Since endangered species cannot be put at risk to measure such effects directly, the species exposed were selected surrogates for endangered species, especially the red-cockaded woodpecker (RCW) endangered in the Southeastern United States. Primary surrogate species included the red-winged blackbird, brown-headed cowbird, and the house sparrow. Endpoint selection was based on individual health indicators, ecological relevance, and life history of the RCW. Both adult and early life stage birds were exposed and monitored for acute and sublethal endpoints. No significant effects were found on the surrogate species, and no significant effects are expected for the RCW under field training conditions. Assessment of obscurants is still in progress and includes physical and chemical characteristics, dispersion, deposition, environmental fate, and the effects of fog oil. The guidelines for the tested protocols will be available in FY00, and the demonstration to provide protocol application and field validation is expected in FY01.

## Resource Monitoring

The management of TES is also a complex issue for military installations involving the synthesis of diverse types of data to develop practical management strategies. Installations are in need of management tools and plans that provide recommendations to address TES issues based on regional habitat information and assessments. Part of that assessment involves the tracking of wildlife as they move throughout their habitats. Under the **Advanced Biotelemetry for Resource Management (CS-759)** project, development of a harmonic radar with "cross band transponder system" will allow continuous monitoring of extremely small birds for up to two years at distances up to 1000 meters. The University of Maryland's Center for Conservation Research & Technology (CCRT) has developed the cross band transponder system which includes compact (1-2 grams), radar-activated VHF transmitters, along with a mobile radar system (visit http://www.ccrt.org/HTML/tech.html). As shown in Figure II-17, the radar system activates the VHF tags on the target species and provides location estimates via an automated computer system for up to two years. Previously unattainable natural history information for wildlife species of interest can be obtained through this technology. This information, assimilated through the use of a geographical information system (GIS), affords maps of animal movements in relation to habitat types, geo-political boundaries, vegetation cover, and many other geographically-oriented data. Furthermore, this technology provides a means to conduct impact assessment on wildlife due to military training and testing without interruption to military operations. This project was recognized and awarded the SERDP Conservation "Project of the Year" Award for FY99 at the *Partners in Environmental Technology* Technical Symposium & Workshop held November 30 - December 2, 1999.

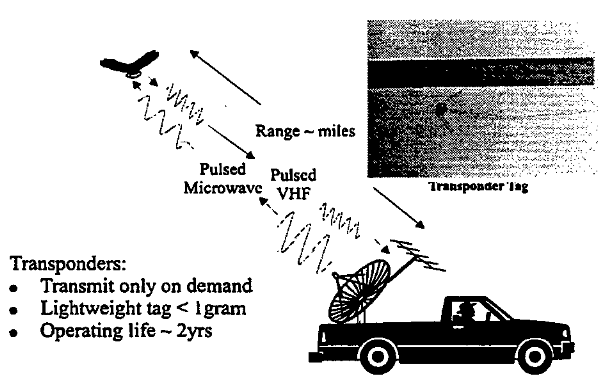



**Figure II-17. Tag and Cross Band Transponder System Concept**

## Resource Management

DoD has developed an integrated, multi-disciplined approach to modeling/decision support for military training and testing lands that supports current activities and planning for future military exercises. For the first time, military planners, trainers/testers, and environmental managers have a framework that provides a comprehensive environment to dynamically evaluate "what-if" scenarios and adaptive strategies that support local, regional, and global sustainment. Developed at Argonne National Lab, this framework for integrated dynamic modeling and simulation is known as the **Object-Oriented Integrated Dynamic Landscape Analysis and Modeling System (OO-IDLAMS) (CS-373)** project. It provides a next-generation computer-based land management support system predicated on the highest level protocols defined by the Army's Land Management System (LMS) initiative. Its flexible object-oriented architecture supports improved dynamic process modeling and provides a powerful decision-support framework for the continued use of training and testing ranges and their long-term sustainment. The framework currently is being used in the resource management arena to dynamically model red-cockaded woodpecker populations. In addition, this innovative approach to integrated modeling and simulation offers substantial cost savings by providing a common and flexible framework to capitalize upon existing DoD investments in models and other software applications, as well as software products developed by private industry and other governmental agencies. The object-oriented integration framework upon which the OO-IDLAMS application is built transparently operates over computer networks and can run on Windows 95/98, Windows NT, and Unix platforms. The OO-IDLAMS prototype is being fielded at Fort Riley, Kansas, and has been presented and demonstrated to several potential user sites (both within the DoD community and to other Federal agencies). Accelerated efforts are under way to prioritize user needs and to pursue technology demonstrations and case studies, by submission of project proposals through DoD's Legacy Resource Management Program, and through partnerships with other agencies. More information can be found at http://www.dis.anl.gov/idlams.

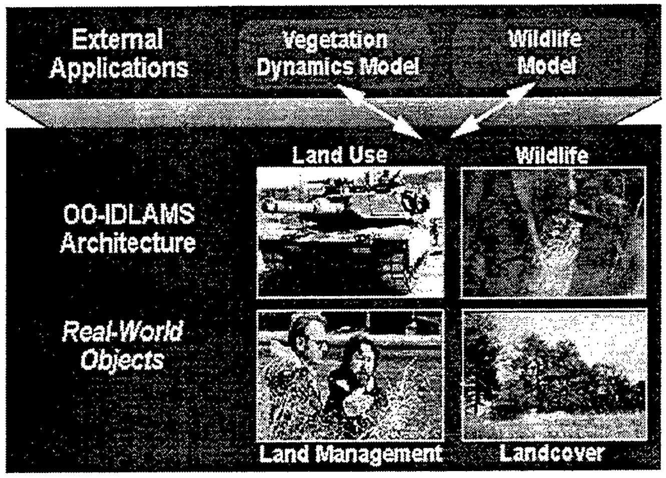



**Figure II-18. OO-IDLAMS Computer Prototype Design**

# Pollution Prevention Accomplishments

## Pesticide Reduction

Using the traditional calendar-based approach to pest control, the DoD currently uses approximately one million pounds of pesticide (active ingredient) annually in three major settings: for warehousing, where material may be stored and treated repeatedly over many months; for facilities, where typical community pest problems may be chronic; and in deployments, where risks from disease vectors are of great concern.

Under SERDP sponsorship scientists working on the **Pesticides Reduction Using Precision Targeting (PP-1053)** project at the U.S. Department of Agriculture's Center for Medical, Agricultural, and Veterinary Entomology have successfully developed an analytical and predictive tool that uses state-of-the-art, commercially available hand-held computers, global positioning system (GPS) and geographical information system (GIS) technologies, and customized software. Through a structured monitoring plan and strategic

placement of toxic baits, "hot spots" of pest activity are easily determined. Instead of spraying every baseboard and corner of the building, pesticide application is limited to toxic bait placement in these "hot spots." Pesticide reductions, estimated between 40 to 90 percent, can be achieved by precision targeting.

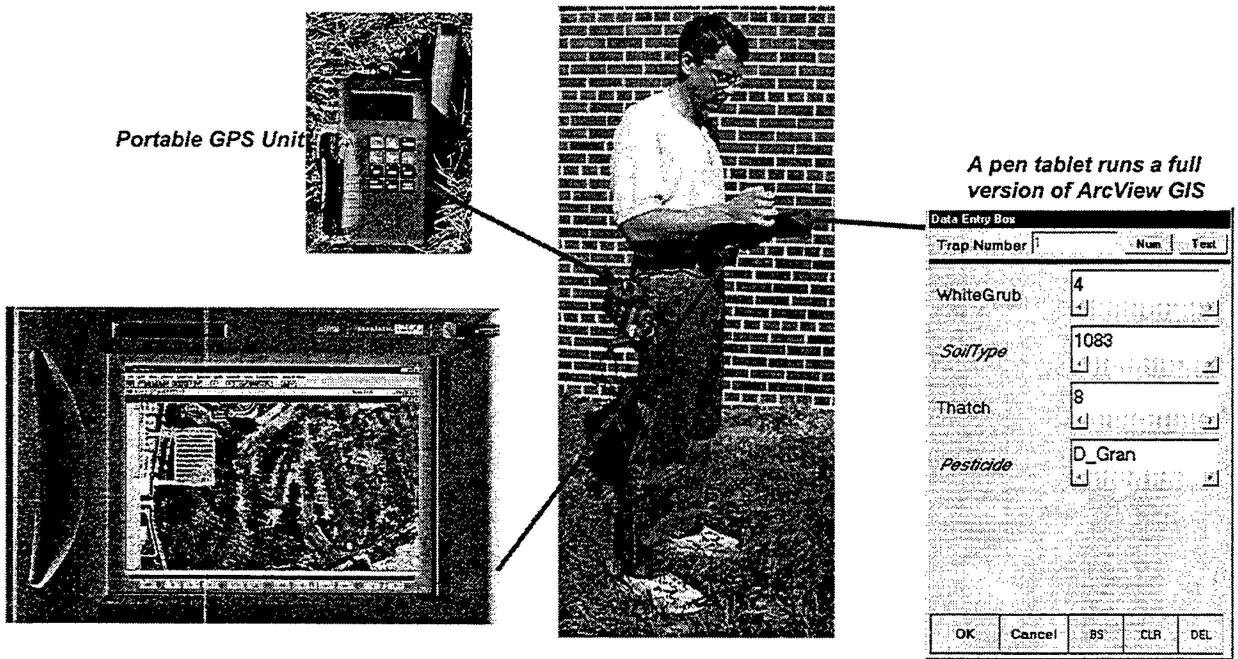



**Figure II-19. New GPS and GIS Tools Promote Precision Targeting**

This SERDP Pollution Prevention project research team has successfully fielded this technology only four years after initiating research and has assisted the Army in mitigating disease and other vector borne illnesses caused by various pests both here and in developing countries. A case in point is Ft. A.P. Hill, VA, the site for the annual Boy Scout Jamboree, where risks from ticks and pesticides used to combat ticks may be significant to these children. Typical operations included spraying large acreage for tick management. With precision targeting, Army Pest Management Practitioners found that only 12 percent of acreage was infested with the Lone Star tick. Precision targeting operations at Ft. A.P. Hill have reduced pesticide use by more than 85 percent. Other DoD transition teams include the U.S. Navy at San Diego for shipboard pest management; the Defense Logistics Agency (DLA) in Alameda, CA, for warehousing; and the Disease Vector Ecology and Control Center at Jacksonville Naval Air Station for evaluating deployment risks from disease vectors.

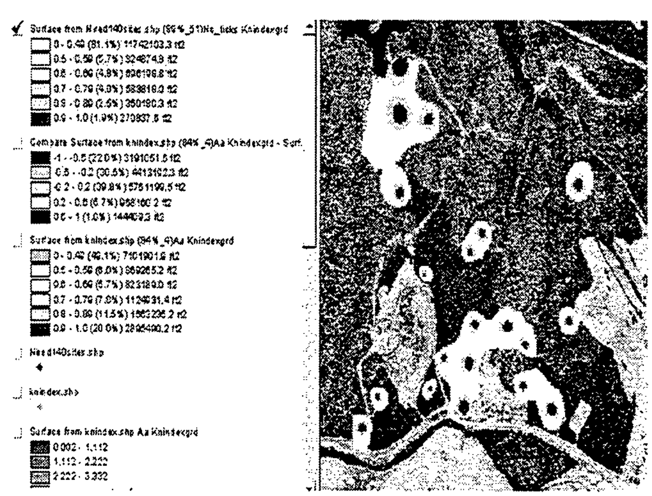


**Figure II-20. Precision Targeting Tick Populations at Ft. A.P. Hill**

This project has clearly become a benchmark project for others to emulate within the Pollution Prevention research and development community for successful transition and implementation in the field. This project was recognized and awarded the SERDP Pollution Prevention "Project of the Year" Award for FY99 at the *Partners in Environmental Technology* Technical Symposium & Workshop held November 30 - December 2, 1999.

# Air Emissions Reduction

The military uses gas turbine engines in all of its aircraft, half of its ships, and many other applications, including tanks, helicopters, and auxiliary power units. These turbine engines are a major source of emissions, such as unburned hydrocarbons, CO, NOx, and sulfur oxide (SOx) at DoD air bases or ports. Gas turbine engines produce pollutants such as NOx, CO, VOCs, and particulate matter under 2.5 microns ($PM_{2.5}$). These pollutants are hazardous to human health and damage our environment by causing smog, acid rain, global warming, and the depletion of the earth's ozone layer. Although military aircraft are exempt from standards that regulate emissions from commercial aircraft, the Department of Defense has had a long-standing policy to make a good faith effort to comply with all applicable environmental regulations.

**Environmental Objectives of the Trapped Vortex Combustor (TVC)**

- To reduce
  - nitrogen oxides (NOx)
  - volatile organic compounds (VOCs)
  - carbon monoxide
  - particulate emissions to 60 percent of EPA's proposed 1996 regulatory levels
- To reduce shipboard (L&M) gas turbine engines NOx emissions by 60% below the level of the LM2500 engine used to power Navy ships

**Other Goals of the TVC**

- To increase fuel efficiency by 3%
- To reduce combustor cost by 25%
- To produce a combustion efficiency above 99% from idle through max power operation
- To improve the lean blow out limit by more than 50% below that of conventional engines

Within the gas turbine engines, the combustor is the main source of emissions. To address this, SERDP is co-sponsoring the **Trapped Vortex Combustor for DoD Engine Applications (PP-1042)** effort through which the Air Force Research Laboratory at Wright-Patterson AFB, OH is working with General Electric (GE) to develop an optimized Trapped Vortex Combustor (TVC) technology that can meet future DoD gas turbine engine environmental and performance needs. The TVC also will be used in GE's Integrated High Performance Turbine Engine Technology (IHPTET) Phase III prototype gas turbine engine.

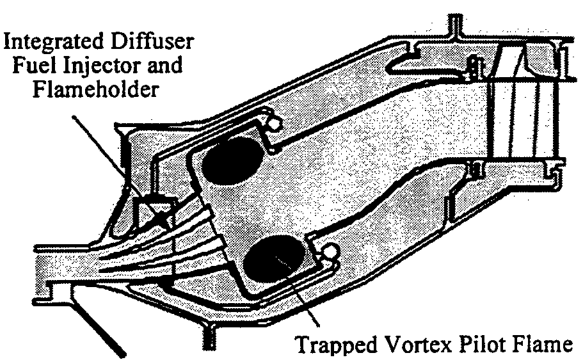



**Figure II-21. Cross-Sectional View of a TVC**

The TVC is a revolutionary design change from the 40-year tradition of using swirl cups to stabilize the flame. Conventional combustors use swirling air to create a recirculation zone that transports hot combustion products back to the combustor face to keep the flame lit. Conventional combustors work well, but they are limited in terms of stability, performance, and pollutant emissions. The idea of trapping a vortex in a cavity to maintain a stable flame originated on an Air Force Office of Scientific Research (AFOSR) program with the Propulsion Directorate of the Air Force Research Laboratory. The TVC maintains a high degree of flame stability because the re-circulation zone or vortex trapped in the cavity is very stable as shown in Figure II-21. The cavity protects the flame zone in the vortex from the high velocity of the main air flow. The TVC serves as a pilot burner and provides a continuous ignition source for the main combustor. Low NOx emissions from a TVC are primarily the result of improved fuel and air mixing in the cavity and front end of the main combustion zone and the short burning length and low residence time made possible by the stability of the TVC.

Results during FY99 from initial high-pressure tests of a 12" rectangular prototypical TVC sector rig demonstrated significant progress toward reaching the emissions and performance goals. For both emissions

and performance, the TVC sector functioned as well or better than current production combustors. This comparison is based on the performance of conventional swirl cup stabilized gas turbine engine combustor designs.

Estimates based on the TVC sector data indicate that Navy ships with a TVC could reduce yearly NOx emissions by 55 percent and VOCs by 50 percent compared to the LM2500 engine. It also demonstrated a 58 percent reduction in lean blow out limit and a 42 percent increase in altitude relight capability for tactical aircraft use. These results are extremely encouraging considering that they were obtained with the first design of a prototypical TVC. Significant emissions and performance improvements are expected with additional research and development. There is also a high probability of transitioning the TVC technology to military as well as commercial gas turbine engines. The Navy and DOE, with help from the SERDP and ESTCP Program Office, are planning a joint program to continue the development and full-scale demonstration of the low-emissions, high-performance TVC technology.

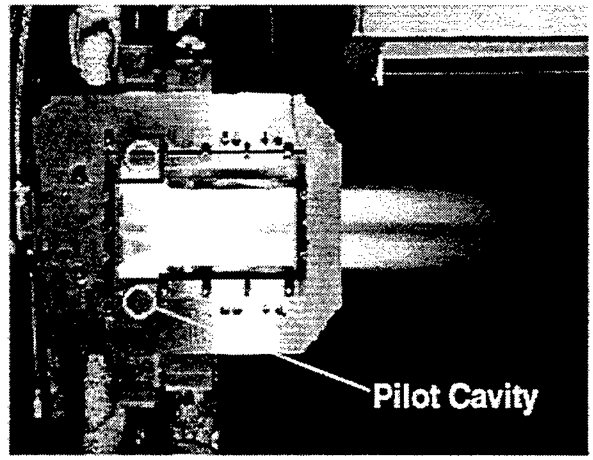



**Figure II-22. Lab Demonstration of a TVC Sector**

## "Natural" Non-Structural Adhesives

Polymeric adhesives are used in a variety of joining applications in the military and civilian sectors. Adhesives currently in use generally contain epoxy-polyamides, polyurethane, polysulfides, or alpha-cyanoacrylates. These adhesives require toxic VOCs to polymerize and, therefore, pose a significant health hazard. The VOCs commonly utilized include toluene, acetone, methanol, ketone, and xylene. Based on Toxic Release Inventory information (1996), it is estimated that 1.6 million pounds of VOCs are released annually through military use of solvent based adhesives. Personnel at manufacturing and repair facilities are at particular risk since the toxic effects of VOCs are evident at concentrations less than parts per million. New adhesives will have to meet the minimum requirements of physical property performance and materials compatibility as generally required by a variety of military specifications and standards.

**Department of Defense Applications**

- Instrumentation Panels
- Optical Assemblies
- Textiles/Fabrics
- Gaskets/Weather Stripping
- Packaging
- Labeling
- Erosion Protection
- Shock Resistant Padding

The project team from Montana Biotech Corporation performing **Non-Structural Adhesives Containing No VOCs (PP-1139)** is investigating novel environmentally benign natural adhesive compounds as viable alternatives to current high VOC solvent borne non-structural adhesives. Natural, biological sources of adhesives have been found in filamentous organisms and thermal mat communities. Cell-to-cell or cell-to-surface adhesion is a basic process that is common to all multi-cellular or communal organisms.

Adhesive polymers identified as part of this project during FY99 are being derived from microorganisms isolated from extreme environments, such as natural hot springs or acid pools. Many cultures have demonstrated 5-15 cm long-fibrous morphology with remarkable tensile strength or biofilms with tenacious surface adhesion.

Unrefined extracellular polymers from 500 microorganisms are being applied to milled aluminum 2024 bolt heads, allowed to cure, and tested for flatwise adhesive strength by Instron analysis. The natural polymers identified during this project will be compared to commercially available adhesives used by the military.

Filamentous organisms

Thermal mat organisms

**Figure II-23. Examples of Natural Adhesive Production by Bacteria**

Thus far, 120 microbial extracts and the three commercially available metrics have been tested. Figure II-24 indicates that the adhesive strength of the baseline compounds is approximately 20-40 pounds per square inch (p.s.i.). The unrefined microbial extracts are arranged according to the pH of microorganism native habitat. The adhesive strength of some of the microbial unrefined extracts exceeds that of the baseline. Numerous unrefined microbial extracts have displayed adhesive strength that exceeds that of currently used high VOC content adhesives, and yet it is estimated that the concentration of adhesive compound in these unrefined extracts is less than 5 percent. Purification to homogeneity may result in far greater adhesive strength. Future studies will involve identification of the microbial adhesive compounds, and testing under various environmental stresses.

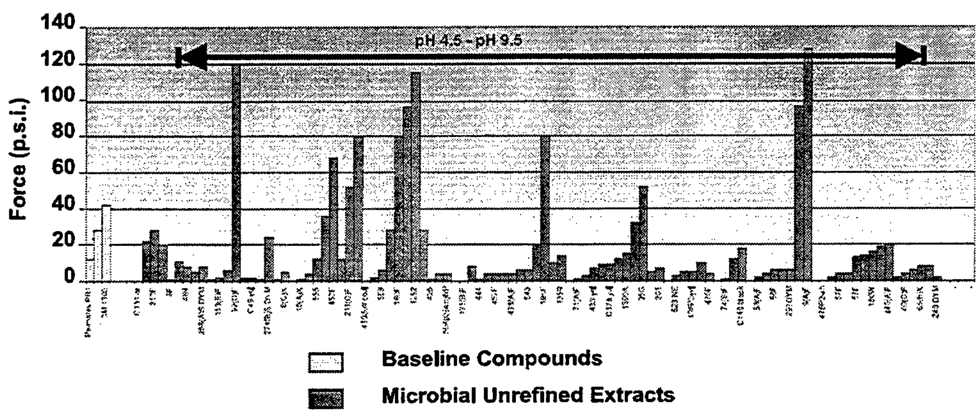



**Figure II-24. Flatwise Adhesive Strength of 1st 100 Unrefined Extracts**

## Green "Small Caliber Ammunition"

SERDP is leveraging DoD Services efforts to find substitutes/alternatives for hazardous materials used in the manufacturing/synthesis of energetic materials and munitions. At U.S. Army Armament Research, Development, and Engineering Center in Picatinny Arsenal, NJ, one such SERDP co-sponsored effort,**Toxic Elimination from Small Caliber Ammunition (PP-1057),** has resulted in a new environmentally friendly Tungsten-based material as projectile core alternative for the current Lead-Antimony mixture which poses lead leachate problems.

> **Green Bullet Production Cost Savings**
>
> Annual savings estimated from the use of Tungsten-based projectile core for small caliber ammunition ranges from \$5M (based on 1 cent per round) to \$30M (based on 5 cents per round).

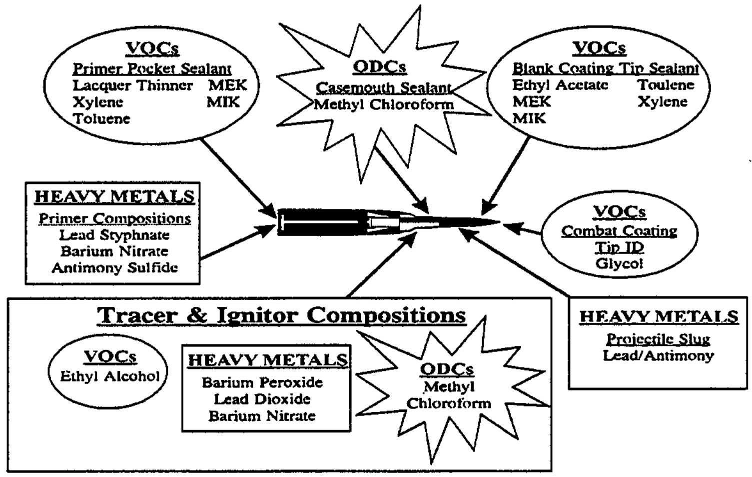



Figure II-25. Green Bullet Target Materials

In FY99, the first production lot of approximately 897,000 Green Bullet 5.56mm M855 cartridges passed Lot Acceptance Testing at Lake City Army Ammunition Plant in Independence, MO. The ammunition will complete packing and subsequently will be ready for distribution to the field. A contract option for an additional 3 million cores was awarded by TACOM-ARDEC and deliveries will begin in March 2000. The yearly cost savings estimated from the use of environmentally sound small caliber ammunition ranges from $5M (based on 1c/round) to $30M (based on 5c/ round). Some other environmentally benign alternatives currently being developed as part of the Green Bullet program include metastable intermolecular composites (MIC) as an alternative to lead containing primers, and environmentally friendly solvents, cleaners, and lubricants needed for charging, loading, cartridge assembly, and packing operations.

## "Green" Coatings Chemistry

Chromates are important chemicals used in forming coatings that protect metals and alloys from corrosion. These coatings are easily applied by immersion, spraying, and brushing metallic surfaces with chromate solutions or chromate-bearing paints. Unfortunately, the primary coating ingredient, hexavalent chromium, is carcinogenic and dangerous in the natural environment. Through the project entitled **Critical Factors for the Transition from Chromate to Chromate-Free Corrosion Protection (PP-1119)**, a team of researchers at Ohio State University (OSU), the Air Force Research Laboratories (AFRL), and the Army Research Laboratories (ARL) is studying the fundamentals of chromate corrosion protection to identify and understand the properties which must be duplicated by non-toxic replacement technologies.

Chromate coatings have been used successfully for more than 50 years by industry and the military. The search for chromate-free technologies has been unsuccessful. To date, no environmentally friendly alternatives, with widespread applicability, have been found. The current opinion among scientists and engineers studying this problem is that a fundamental understanding of the mechanisms as well as the strengths and weaknesses of current chromate coating technology is required to properly develop non-toxic alternative technologies that meet or exceed the future corrosion protection needs.

The primary focus of the OSU-AFRL-ARL team is on how inorganic and organic chromate-bearing coatings provide corrosion protection for aluminum alloys. In general, coatings prevent corrosion by serving as barriers that separate the metal from the environment. Chromate coatings have an extra corrosion inhibitor built-in, hexavalent chromium. Hexavalent chromium can be leached from the coatings into an attacking solution where it acts to protect metal exposed because of mechanical or chemical damage to the coating. In this sense, chromate coatings are self-healing.

Many factors can act singly or in combination to reduce the effectiveness of self-healing chromate coatings. For example, most aluminum alloys contain transition metal alloying additions that are concentrated into small 0.1 to 10 μm diameter intermetallic compound particles. These particles do not always receive the coating properly during fabrication and can be sites for coating failure. Figure II-26 shows a spatially resolved Raman map of chromate conversion coating formation on an Al-Cu-Mg ingot specially prepared to contain a family of intermetallic compounds found in high strength Al alloys used in aircraft. Coating

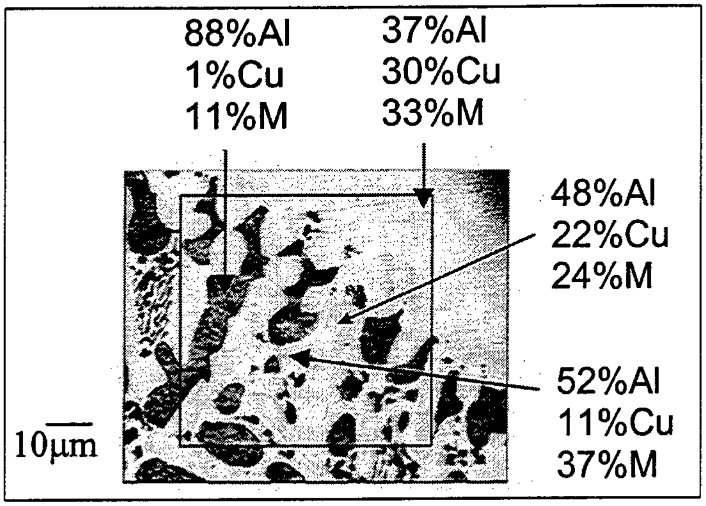



**Figure II-26. Copper (Cu) Rich Intermetallic Particles Encourage Incomplete Coating Formation**

formation is high on Cu-poor phases but low on Cu-rich intermetallic phases. In commercial Al-Cu-Mg alloys coating formation is suppressed on Cu-rich particles. Incomplete coating formation is the result of an unexpected interaction of the Cu-rich phases with a minor ingredient in the coating bath and results in reduced overall corrosion resistance. Additionally, chromate coatings, once applied to a metal surface, will age with time. The aging process induces chemical changes that inhibit the release of hexavalent chromium, which limits their ability to self-heal. These issues among others are the subject of the OSU-AFRL-ARL research team. This four-year SERDP project is entering its second year in FY 2000.

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# III. PROGRAM DESCRIPTION

## General

This section provides an overview of each of the SERDP Thrust Area Programs and planned initiatives for research. Topics include the goals of each Thrust Area, the environmental and operational drivers directing needed technologies, and the major areas of research and development (R&D) within each Thrust Area. Each FY 1999 and FY 2000 project is listed according to subtopic categorization and completion status.

The SERDP Program contains the following four Thrust Areas: Cleanup, Compliance, Conservation, and Pollution Prevention. Each year the Executive Director, with the assistance of the Executive Working Group (EWG) and the Scientific Advisory Board (SAB), determines the funding balance between these four Thrust Areas. Figure III-1 illustrates the distribution of funds to specific Thrust Areas for FY 1999 and FY 2000.

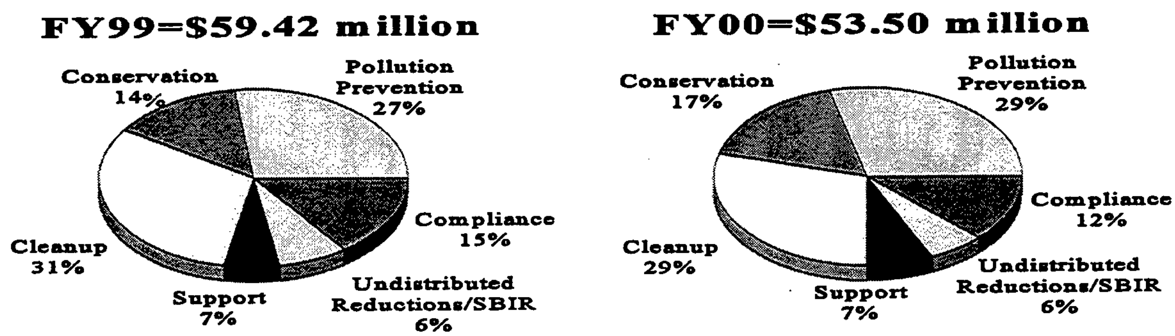



**Figure III-1. Total SERDP Funding by Thrust, FY 1999 – FY 2000**

NOTE: FY99 values represent actual funding. FY00 values are planning figures based upon the President's Budget Request.

## Program Development

SERDP funds environmental research and development through a competitive process in accordance with the established Congressional direction and is further guided by policies provided by the SERDP Council. There are two solicitations annually. One is the major, or core, solicitation and provides funding in various amounts for multi-year projects. The other is the SERDP Exploratory Development program, or SEED, program designed to provide initial funding for high-risk, high-payoff projects. SEED projects are limited to a one year time period and a maximum of $100,000 in funding.

**SERDP PROJECTS**

| FY 1999 | |
|---|---|
| 88 | Total projects |
| 19 | Completed projects |
| 24 | New Start projects |

| FY 2000 | |
|---|---|
| 102 | Total projects |
| 28 | Completing projects |
| 34 | New Start projects |

Because both government and private sector parties may compete for SERDP funds, there are two announcements for each solicitation: (1) a Call For Proposals to the Federal sector and (2) a Broad Agency Announcement (BAA) for the private sector. In both of the FY 2000 Federal Call For Proposals, participating organizations and their laboratories were asked to solicit proposals that responded to the high-priority defense environmental needs as identified in the Statements of Need which reflect the requirements developed by the Deputy Under Secretary of Defense for Environmental Security DUSD(ES). Each Federal organization conducted its own internal down-select procedure and forwarded its best proposals to SERDP for consideration. The BAAs requested direct

submission of proposals in response to the same DoD environmental needs from non-Federal participants from industry, non-profit entities, and academia. Both the core and SEED BAA solicitations appeared in the Commerce Business Daily.

Each year, a peer review panel is used in the core solicitation to assist in the down-select of Federal and non-Federal proposals. Following the peer reviewers' evaluation of technical merit and personnel, SERDP's multi-agency Technology Thrust Area Working Groups (TTAWG) were tasked with reviewing both the Federal and non-Federal submissions of both solicitations for all evaluation criteria. All proposals recommended by the TTAWGs and approved by the Executive Director were briefed to the SERDP SAB for approval prior to Council approval. Titles of these projects may be found in the lists of FY 2000 New Start Projects within each Thrust Area description section, and summaries of each new project are located in Appendices A through D.

# CLEANUP

## Introduction

The Department of Defense (DoD) and the Department of Energy (DOE) must protect human health and the environment, reduce remediation costs, and provide timely cleanup. Cleanup goals for the DoD are:

- To attend to imminent threats to public health and safety;
- To remediate all defense sites having a significant public health risk as quickly as feasible within the constraints of available resources; and
- To expedite transfer of base realignment and closure (BRAC) sites and formerly used defense sites (FUDS) to future owners.

The DoD and DOE have a legal obligation to meet the Federal, state, and local environmental protection and public health regulations. Both organizations own and operate thousands of installations, ranging from training bases to industrial production plants. Many of these installations have been operating for half a century or longer. During most of this time the agencies, like much of American industry, operated their facilities without full respect for the environment or an understanding of potential impacts.

Using today's technology, the cost to remediate DoD sites alone is estimated at $35 billion [excluding unexploded ordnance (UXO) sites], and total cost of cleanup at current and former defense sites (including DOE sites) is projected to exceed $200 billion. Experience with past remediation technology development has demonstrated a significant return on investment. Defense environmental managers require cost-effective and timely remediation capabilities that focus on assessment, characterization, and treatment. Each DoD Service has submitted its User Requirements for Cleanup, which are prioritized in the DoD Environmental Technology Requirements Strategy. These requirements can be categorized into specific environmental concerns. Within the Cleanup Technology Thrust Area, the primary environmental concerns are the need to:

- Implement timely, effective, and affordable methods for site characterization, including detection and discrimination of UXO;
- Ensure the use of effective, affordable remediation technologies; and
- Comply with various Federal, state, and local regulations for site remediation.

These concerns are addressed by the Cleanup subthrusts and research areas as depicted in Figure III-2.

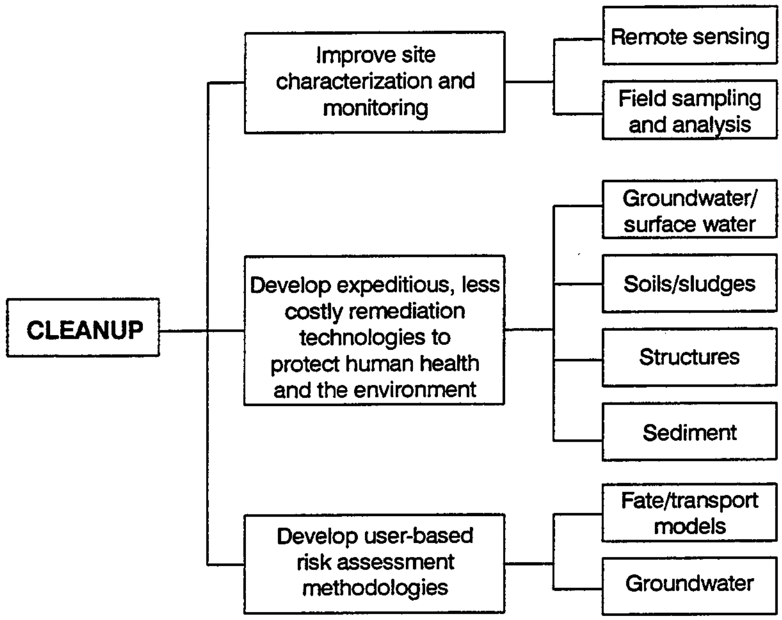



**Figure III-2. Cleanup Taxonomy**

Figure III-3 shows the FY 1999 and FY 2000 Cleanup funding by subthrust area. For FY 1999, the Cleanup Technology Thrust Area received approximately 31 percent of the SERDP budget. While many defense cleanup situations will require that technologies be identified in the near-term, additional research in this area has the potential to provide the highest return on investment. Congress appropriated funds in FY 1999 specifically to conduct efforts investigating environmental toxicology. This project is represented under the "Other" category in Figure III-3.

| CLEANUP | |
|---|---|
| **FY 1999** | |
| 32 | Total projects |
| 5 | Completed projects |
| 9 | New Start projects |
| **FY 2000** | |
| 41 | Total projects |
| 9 | Completing projects |
| 15 | New Start projects |

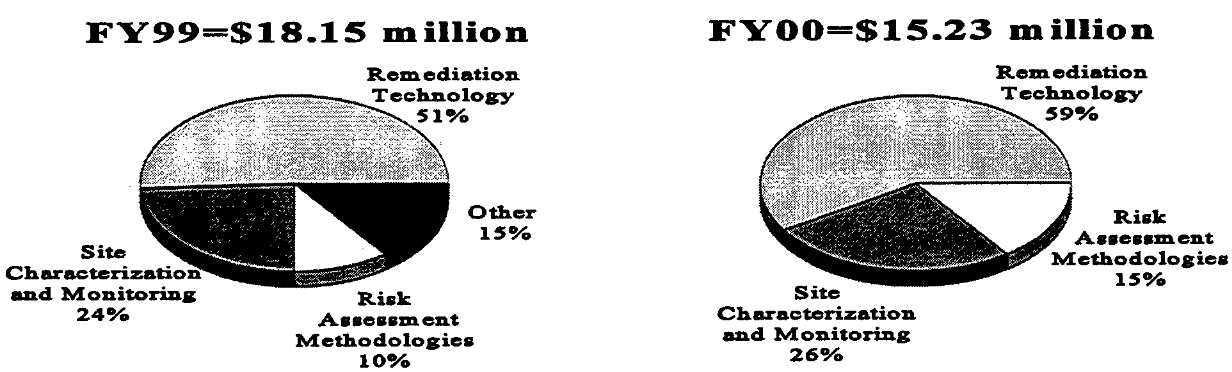



**Figure III-3. SERDP Cleanup Funding by Subthrust, FY 1999 – FY 2000**

NOTE: FY99 values represent actual funding. FY00 values are planning figures based upon the President's Budget Request.

## Principal Driving Requirements

The first subthrust area in Cleanup seeks to develop improved and less costly site investigation technology for locating and characterizing wastes. Within this subthrust, the location, identification, and remediation of UXO has been identified by the Services as the highest priority user need. It poses an enormous challenge to the effective cleanup of many DoD sites, primarily on land but also under water. Current estimates indicate that up to 11 million acres of land in the U.S. are suspected to contain UXO as a result of military training and weapons testing activities -- 6 million acres of UXO contaminated Army and Navy land, approximately 5 million acres on Department of Interior land, and at least 50 sites at sea. These lands represent a full range of terrains, vegetative cover, soil types, and geophysical characteristics. The present cost, driven largely by the need to exercise extreme safety precautions, ranges from $1,500 per acre for surface UXO to at least $5,000 per acre for sub-surface ordnance.

Identifying and characterizing sites contaminated with chlorinated solvents is another significant issue to the DoD. Chlorinated solvents represent a class of contaminants that are detected at more DoD sites than any other contaminant group. Chlorinated solvents, predominantly perchloroethylene and trichlororthylene, have been used in massive quantities over the last four decades. Release of these liquids to the environment accounts for a significant portion of the contaminated sites requiring cleanup. These contaminants have migrated through the subsurface and entered groundwater at more than 50 percent of the contaminated DoD sites. There is a comparable degree of contamination at DOE and private industry Superfund sites. Estimated annual costs exceed $500,000 for containing and monitoring a single dense non-aqueous phase liquid (DNAPL) plume. Novel technologies to detect and characterize these plumes will significantly reduce these costs.

The second Cleanup subthrust focuses on the need to develop expeditious, less costly remediation technologies. Remediation of subsurface contamination of both soils and groundwater remains a high priority at DoD facilities. Groundwater is mobile and can spread contamination off base. Therefore, this subthrust is directed primarily at developing innovative technologies to address groundwater remediation more effectively. Current groundwater treatment strategies typically employ pump-and-treat technologies which are expensive to operate and are very slow to achieve lasting cleanup. Major limitations to the use of conventional pump-and-treat technology relate to difficulties in extracting contaminants from source areas where non-aqueous phase liquids (NAPL) exist. Furthermore, presently employed technologies applied in pump-and-treat, such as air stripping or activated carbon treatment, do not result in final destruction of contaminants.

The challenges facing those involved with the nearly 17,000 sites on DoD installations potentially requiring environmental remediation include: (1) distinguishing those sites that pose significant environmental risks from those that pose little risk; (2) prioritizing contaminated sites by the degree of risk posed; (3) quantifying the risks at each site; and (4) developing appropriate remedial actions and cleanup goals. Development of improved techniques for risk assessment, which provides a logical framework for making such decisions, is a DoD priority and the focus of this third Cleanup subthrust. The effectiveness of existing methods will be expanded by research directed at problems particularly evident at DoD installations.

Under this third Cleanup subthrust, SERDP recognized the importance of dedicating funding for research that would aid in the establishment of environmentally acceptable endpoints (EAE) applicable to DoD contaminants of concern such as chlorinated solvents, organic compounds associated with explosives, and metals. The SERDP Council endorsed a Scientific Advisory Board (SAB) recommendation to organize an EAE workshop. The workshop was held in June 1998 and included 63 engineers and scientists with recognized experience participating in EAE Working Groups. The research objectives identified by the EAE Working Groups served as the foundation for two of the SERDP Statements of Need (SON) that were released to the public in FY99. Consequently, those proposals responding to these SONs in FY99 have received a thorough peer review evaluation and the successful projects will be initiated in FY00 as New Start Projects.

Two projects have been approved for funding under the SON *Bioavailability and Long-term Stability Issues Associated with Metals in Soils*: 1) **Extraction Tests for Determining the Bioavailability of Metals in Soil (CU-1165)** and 2) **Quantifying the Bioavailability of Toxic Metals in Soils (CU-1166).** Likewise, three projects have been approved for funding under the SON *Establish Better Understanding of Aerobic and Anaerobic Transformation of cis-Dichlorethene (cis-DCE) and Vinyl Chloride (VC)*. These are: 1) **Aerobic and Anaerobic Transformation of cis-DCE and VC: Steps for Reliable Remediation (CU-1167)**; 2) **Characterization of the Aerobic Oxidation of cis-DCE and VC in Support of Bioremediation of Chloroethene-Contaminated Sites (CU-1168)**; and 3) **Factors Affecting cis-DCE and VC Biological Transformation Under Anaerobic Conditions (CU-1169).** More information on any of these five new initiatives can be found in Appendix A. In addition, SERDP has continued to pursue the research objectives identified by the EAE Working Groups. Specifically, the research objectives have served as the foundation for two of the SERDP SONs released to the public in the FY01 Program Solicitation. A description of these EAE-related FY01 Cleanup SONs can be found in Appendix E.

Leveraging with other defense science and technology programs and industry, the Cleanup Technology Thrust Area focuses on the following R&D objectives:

- Develop reliable and cost effective means to identify, assess, and clean lands and underwater areas (inland, estuarian, and marine) contaminated with unexploded ordnance;
- Develop investigation methods and technologies that are capable of locating and characterizing wastes in a timely, cost effective, and quality manner;
- Develop innovative, compliant technologies that reduce remediation costs for sites containing explosives, propellants, fuels, solvents, heavy metals, organic contaminants, and other inorganic contaminants;
- Facilitate transfer of cleanup technologies to field use. This includes, but is not limited to encouraging the use of the National Environmental Technology Test Sites;
- Develop cost-effective methods and tools to determine fate, transport, and effects of significant defense-related contaminants;
- Develop risk-based modeling and simulation methods for hazard assessment and establishing cleanup priorities and scientifically defensible cleanup levels; and
- Develop scientifically defensible EAEs for DoD chemicals of concern, including chlorinated organics, organics associated with explosives, and heavy metals, to facilitate risk-based cleanups at DoD sites.

## Cleanup Program

The following list reflects FY 1999 completed projects and projects continuing into FY 2000. Also included are titles of projects that begin in FY 2000. Complete descriptions of all of the projects for FY 1999 and FY 2000 may be found on the pages referenced in Appendix A - Cleanup Project Summaries.

### Subthrust 1 - *Improve Site Characterization and Monitoring*

Page

**FY 1999 Completed Projects**

Unexploded Ordnance (UXO) Detection by Enhanced Harmonic Radar ............... A-18

Model-Based Data Fusion and Discrimination of UXO in Magnetometry and EM Surveys ................................................. A-28

**FY 2000 Continuing Projects**


Low-Frequency Ultra-Wideband Boom Synthetic Aperture Radar (Boom-SAR) for Remote Detection of Unexploded Ordnance (UXO) ........ A-17
Negative Ion Sensors for Real-Time Downhole DNAPLs Detection ........ A-24
Integrated Geophysical Detection of DNAPL Source Zones ........ A-26
Innovative Seismic System for Buried Unexploded Ordnance Detection and Classification ........ A-27
Environmental Impacts to the Chemical Signature Emanating from Buried UXO ........ A-31
Processing Techniques for Discrimination between Buried Unexploded Ordnance and Clutter Using Multisensor Array Data ........ A-34
UXO Discrimination by Mid-Frequency Electromagnetic Induction ........ A-36
Statistical Signal Processing with Physics-Based Models: Multi-Sensor UXO Detection and Identification ........ A-38
Nonintrusive Characterization of Dense Nonaqueous Phase Liquids Using Short-Lived Radiotracers in Partioning Interwell Tracer Tests ........ A-46


**FY 2000 New Start Projects**


Assessment of the Potential for Microgravimetry in Remote Discrimination and Identification of Buried UXO *(SEED project)* ........ A-66
Multiple Frequency Induction Measurements for Enhanced Buried UXO Discrimination *(SEED project)* ........ A-68
Novel Acoustic Technique for UXO Discrimination *(SEED project)* ........ A-70
SAR/GPR Matched Filter Processing for UXO Discrimination *(SEED project)* ........ A-72
Detection and Classification of Buried Metallic Objects *(SEED project)* ........ A-73


## Subthrust 2 - *Develop Expeditious, Less Costly Remediation Technology*

**FY 1999 Completed Projects**


Value-Added Site Monitoring & Infrastructure Maintenance for In-Situ Bioremediation ........ A-21
Novel Approach for Stimulating Reductive Dechlorination ........ A-78


**FY 2000 Continuing Projects**


Aquifer Restoration by Enhanced Source Removal ........ A-3
Federal Integrated Biotreatment Research Consortium (FIBRC): Flask to Field Initiative ........ A-5
National Environmental Technology Test Sites (NETTS) Program
NETTS Program - McClellan AFB, CA ........ A-7
NETTS Program - Naval Construction Battalion Center, Port Hueneme, CA ........ A-8
NETTS Program - Former Wurtsmith AFB, MI ........ A-9
NETTS Program - Dover AFB, DE ........ A-11
Development of Simulators for In-Situ Remediation Evaluation, Design, and Operation ........ A-13
Bioenhanced In-Well Vapor Stripping to Treat Trichloroethylene ........ A-15
In-Situ Clay Formation: A New Technology for Stable Containment Barriers ........ A-29
Assessment and Prediction of Biostabilization of Polycyclic Aromatic Hydrocarbons (PAH) in Sediments ........ A-33
An Innovative Passive Barrier System Using Membrane-Delivered Hydrogen Gas for the Bioremediation of Chlorinated Aliphatic Compounds ........ A-40
Influence of Groundwater Constituents on Longevity of Iron-Based Permeable Barriers ........ A-42
Development of Effective Aerobic Cometabolic Systems for the In-Situ Transformation of Problematic Chlorinated Solvent Mixtures ........ A-44
Evaluation of Performance and Longevity at DoD Permeable Reactive Barrier Sites ........ A-49

**FY 2000 New Start Projects**


In-Situ Bioreduction and Removal of Ammonium Perchlorate .......................... A-52
In-Situ Bioremediation of Perchlorate .......................... A-54
In-Situ Bioremediation of Perchlorate-Impacted Groundwater .......................... A-56
Aerobic and Anaerobic Transformation of cis-DCE and VC: Steps for Reliable Remediation .......................... A-61
Characterization of the Aerobic Oxidation of cis-DCE and VC in Support of Bioremediation of Chloroethene-Contaminated Sites .......................... A-63
Factors affecting cis-DCE and VC Biological Transformation Under Anaerobic Conditions .......................... A-64
Fe(O)-Based-Bioremediation of RDX-Contaminated Aquifers *(SEED project)* .......................... A-75
In-Situ Remediation of Explosives Contaminated Groundwater with Sequential Reactive Treatment Zones *(SEED project)* .......................... A-77


## Subthrust 3 - *Develop Risk Assessment Methodologies*

**FY 1999 Completed Projects**

None

**FY 2000 Continuing Projects**


Using Mode of Action to Assess Health Risks from Mixtures of Chemical/Physical Agents .......................... A-19
Genosensor-Based Ecotoxicity Response Assessment .......................... A-22
Biological Assessment for Characterizing Contaminant Risk at the Genetic-, Individual-, Population-Level .......................... A-47


**FY 2000 New Start Projects**


Proposal to Develop Extraction Tests for Determining the Bioavailability of Metals in Soil .......................... A-57
Quantifying The Bioavailability of Toxic Metals in Soils .......................... A-59


## Other

**FY 1999 Completed Projects**


Environmental Toxicity Earmark .......................... A-50


# FY 2001 Cleanup Initiatives

Detection and discrimination of UXO continues to be a major research priority in the Cleanup Thrust Area. To this end, a FY 2001 SON, **Statistical Sampling for UXO Site Characterization**, has been issued. Through this SON, SERDP looks to fund development of scientifically sound sampling procedures that can exploit modern geophysical surveying techniques to characterize sites potentially contaminated with UXO. Statistically valid sampling approaches are needed for the cost-effective investigation of UXO-contaminated sites. The footprint required for detailed geophysical surveys can be reduced if sub-sampling procedures can distinguish, with high confidence, the boundaries of contamination within larger sites. Results from this work will provide the data necessary to evaluate the scientific validity and to predict the cost savings and potential risks of the proposed sampling procedure, as compared to currently used techniques.

A second FY 2001 proposed area of new research is entitled **Remediation Strategies to Enhance In-Situ Mixing of Contaminants and Chemical/Biological Additives**. The purpose of this SON is to solicit

proposals to develop engineering strategies to enhance the in-situ remediation of subsurface groundwater contamination by facilitating in-situ mixing. Through this SON, SERDP intends to fund improved delivery systems and methodologies for chemical and/or biological additives in the subsurface that will overcome the limited extent of mixing that is achieved with current methods. The expected payoff of this proposed work is the development of a greater understanding of, and improved methods to, enhance in-situ mixing of contaminants and chemical and/or biological additives. This will help facilitate the establishment of more cost-effective and efficient remediation technologies that are protective of human health and the environment.

Another proposed new initiative is focused on and entitled **In-Situ Management of Contaminated Marine Sediments**. The objective of this SON is to fund development of innovative technologies that support the cost-effective, in-situ, non-removal management of contaminated marine sediments. Research and development proposals are sought for the characterization, monitoring, in-situ remediation, and/or containment of contaminated marine sediments. Potential research efforts could focus on: (1) technologies for rapid, accurate cost effective characterization of sediments; (2) technologies for in-situ remediation of sediments through either biotic or abiotic means; (3)stabilization/containment technologies which significantly reduce the bioavailability of contaminants; and/or (4) monitoring technologies to assess the performance of in-situ treatment and/or containment technologies and the status of contaminated sediments not requiring active remediation. Results from this work will provide the data necessary to prove the scientific feasibility and predict the economic feasibility of the proposed characterization, monitoring, in-situ remediation or containment approach for contaminated sediments.

The fourth proposed new initiative is focused on and entitled **Development of Ecological Soil Screening Levels**. The purpose of this SON is to fund research and development to support the establishment of risk-based soil screening levels for ecological receptors. The work should address one or both of the following specific objectives: (1) the relationships between contaminant concentrations in soil and soil biota toxicity, and/or (2) the characterization of bioavailability across trophic levels. This research will directly support the development of Ecological Soil Screening Levels (eco-SSL). The availability of EPA-accepted, ecologically based screening levels for contaminants in soils will result in significant cost-savings in performing ecological risk assessments at DoD and non-DoD sites, and promote greater consistency in the way such assessments are conducted.

The last core FY 2001 proposed area of new research is **Microbial Processes for the Degradation of Nitroaromatic Contaminants**. Through this SON, SERDP intends to fund research to increase the fundamental understanding of the microbial processes involved in the degradation of nitroaromatic contaminants and search for ways to improve on these natural capabilities via metabolic engineering. Results from this research should improve the ability to predict and enhance the in-situ biodegradation of nitroaromatic compounds in soil and groundwater. The expected payoff of proposed work includes development of a greater understanding of the microbial processes involved in the degradation of nitroaromatic contaminants that will help facilitate the establishment of more cost-effective and efficient remedial action plans that are protective of human health and the environment. The improved nitroaromatic degradation approaches that will be developed through this SON will improve the reliability of contaminant treatment processes and expedite the cleanup and successful closure of energetics-contaminated DoD sites.

In addition to the core SONs discussed above, SERDP has solicited proposals in response to two Cleanup SEED SON topics. Through the first SEED SON, SERDP intends to fund research in **UXO Detection and Discrimination Data Processing** in order to support advances needed in the detection and discrimination of UXO. Specifically, items ranging from 20-mm shells to 2000-lb bombs must be detected and discriminated from other non-hazardous items in the subsurface. Algorithms are needed that can exploit data from current state-of-the-art sensors and advanced sensors that are now becoming available. The funded SEED proposals will explore new discrimination techniques and their application to data collected under other ongoing programs.

The second SEED SON solicitation intends to fund research in **Long-Term Monitoring (LTM)**. The cost of long-term monitoring of contaminated sites is a significant and growing portion of the DoD cleanup program budget. Consequently, advances are needed in sensor and supporting technologies (i.e., sampling and data collection) to significantly reduce these costs. The primary area of interest is monitoring ground water contamination. The funded SEED efforts should explore the proof-of-concept for new long-term monitoring technologies. Technology development efforts to minimize person hours in the field through new sampling to eliminate purging from monitoring wells, automation of sampling activities, and in-situ sensors are of interest.

Detailed descriptions of the FY 2001 Cleanup Statements of Need may be found in Appendix E.

# COMPLIANCE

## Introduction

Within the United States, the DoD must comply with Federal environmental protection laws such as the Clean Water Act (CWA), the Clean Air Act and Amendments (CAAA), and the Resource Conservation and Recovery Act (RCRA), as well as state and local regulations. These laws result in specific requirements for the treatment of emissions and disposal of wastes generated during DoD operations, including those generated by vehicles, aircrafts, and vessels, as well as the open burning and open detonation (OB/OD) of waste energetics.

At the international level, the International Maritime Organization's Marine Pollution Convention (MARPOL) Annexes (to which the United States subscribes) may restrict or prohibit DoD operations in international waters and MARPOL Special Areas unless vessels meet international environmental statutes. In addition, countries that host DoD facilities are implementing and enforcing compliance with regulations and standards that may restrict or prohibit DoD operations in foreign ports and bases.

Virtually all DoD activities and assets are subject to compliance with these environmental statutes and regulations. Therefore, the dual DoD Compliance goals are:

- To ensure that all applicable environmental rules and regulations are met; and
- To reduce or eliminate the chances for Notices of Violation (NOV).

Affected DoD activities and assets include combat testing and training; operational installations; ordnance and weapons manufacturing and disposal; repair and rebuilding installations; and ship and aircraft operations. DoD is projected to spend between $2 and $3 billion annually for environmental compliance, requiring monitoring and treatment of DoD emissions and wastes. New technologies must be developed to reduce this cost and enable the DoD to comply fully with increasingly stringent requirements while fulfilling its mission unencumbered by regulatory fines, restricted access or mobility, or negative public reactions. In addition, full compliance with environmental regulations is a critical step in DoD's initiative to achieving and maintaining sustainability.

Therefore, the mission of the Compliance Technology Thrust Area in SERDP is to research and develop new technologies to support waste treatment and disposal, environmental monitoring, and environmental management. These areas are not to be directly related to site restoration but are related to meeting current and future environmental compliance requirements of DoD and DOE. They include end-of-pipe recycling (i.e., waste that is reused for other than its original purpose). Further, they address understanding the fate and transport of defense-related air and wastewater discharges. These technologies do not include elimination of waste streams through substitution or process modification which are included in the Pollution

Prevention Thrust Area. Technologies related to site restoration are addressed in the Cleanup and Conservation Thrust Areas.

The primary concerns in this technology thrust area include deterioration or loss of operational capability and the high costs of regulatory compliance. Each of the uniformed Services has submitted its User Requirements for Compliance, which are based on existing environmental protection laws and prioritized in the DoD Environmental Technology Requirements Strategy (DETRS). These primary DoD environmental concerns reflect the need to:

- Better characterize DoD wastes;
- Measure and monitor air emissions and wastewater/sludge discharges;
- Control shipboard and land-based sources of liquid and solid waste;
- Develop effective treatments of hazardous waste;
- Reduce emissions of hazardous air pollutants; and
- Develop improved fate and transport prediction capabilities for emissions and/or discharges of specific compounds or contaminants.

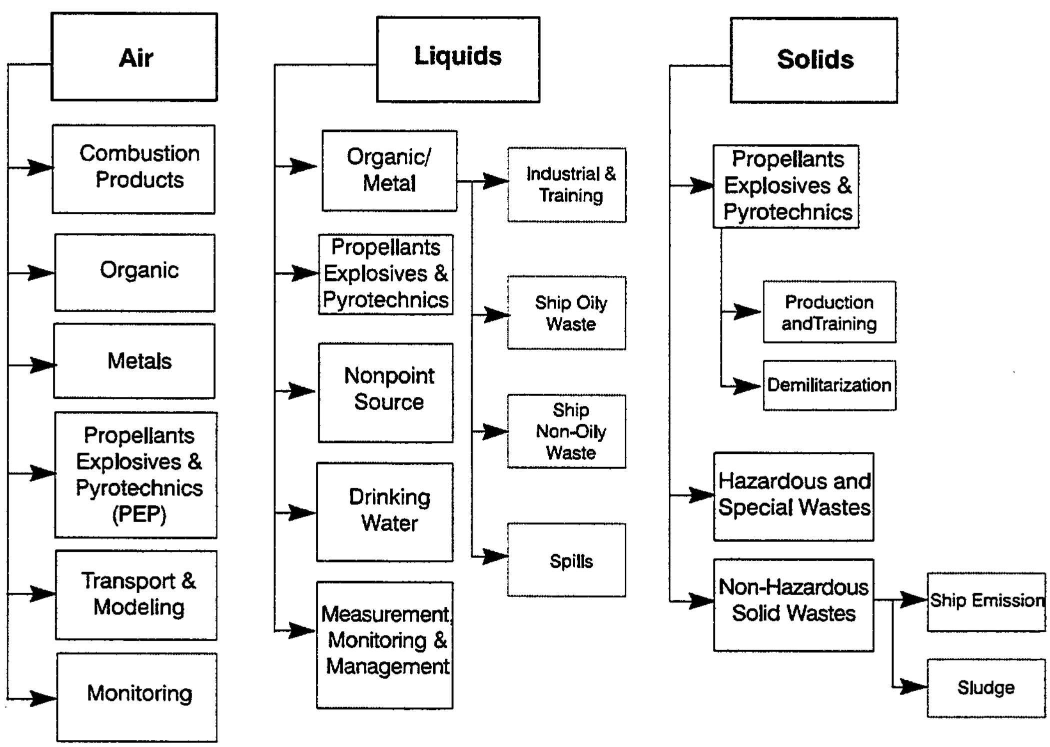



**Figure III-4. Compliance Taxonomy**

Each of these User Requirements respond to specific environmental regulations that have been developed under the CAAA, the CWA and amendments, and, for solid and hazardous wastes, the RCRA. Given the compliance requirements that result from these three major laws and their amendments, as well as related standards, SERDP addresses Compliance according to the following three major subthrust areas related to

affected environmental media: air, liquids, and solids. Each of these media are further subcategorized into specific types of wastes, pollutants, monitoring actions, or processes as illustrated in Figure III-4. Noise as a subthrust area now comes under the Conservation Thrust Area.

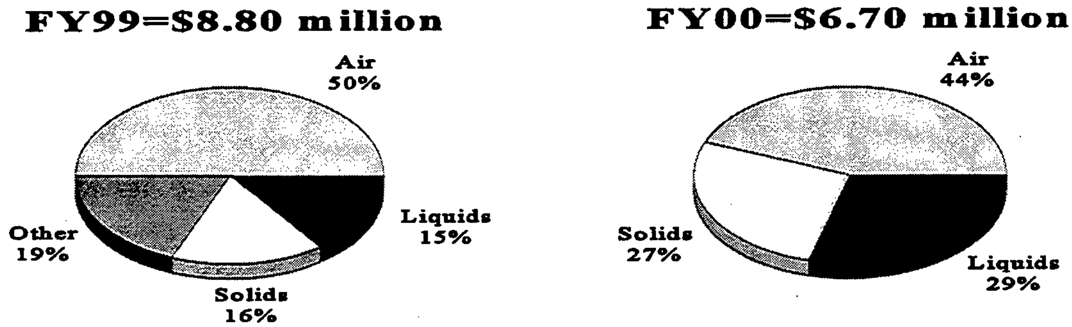



**Figure III-5. SERDP Compliance Funding by Subthrust, FY 1999 – FY 2000**
NOTE: FY99 values represent actual funding. FY00 values are planning figures based upon the President's Budget Request.

Figure III-5 shows Compliance funding by subthrust area for FY 1999 and FY 2000. For FY 1999, Compliance received approximately 15 percent of the total SERDP budget. A slight decrease in SERDP's Compliance Technology Thrust Area investment is anticipated over the next five years, although this could change with the implementation of new environmental regulations. Congress appropriated funds in FY 1999 specifically to conduct efforts in support of health and safety training aspects related to persons undertaking remediation work, including the scrapping of Navy ships. This project is represented under the "Other" category in Figure III-5.

| COMPLIANCE | |
|---|---|
| **FY 1999** | |
| 17 | Total projects |
| 6 | Completed projects |
| 4 | New Start projects |
| **FY 2000** | |
| 17 | Total projects |
| 6 | Completing projects |
| 6 | New Start projects |

## Principal Driving Requirements

For FY99, SERDP responded to requirements resulting from specific regulatory developments within the three Compliance subthrusts. For the air subthrust, DoD must develop new and effective measuring/monitoring and treatment/control technologies for air emissions resulting from DoD activities. In the course of implementing the CAAA of 1990, a number of local air quality jurisdictions (many facing non-attainment status for one or more priority pollutants) have imposed local standards that are more stringent than national emissions standards. The employment of military-unique systems such as liquid-fuel rockets, military jet engines, and mobility equipment will require that DoD treat and control emissions of NOx, ultrafine particulate matter (PM), volatile organic compounds (VOC), and hazardous air pollutants (HAP) at DoD installations. One difficulty associated with monitoring and controlling these emissions is that they frequently are episodic or high-volume and low-concentration, such as jet engine test cells, painting, stripping, and cleaning operations. Existing CAAA regulations and anticipated future restrictions on NOx, ultrafine PM, VOCs, and HAPs are testing the limits of existing emissions monitoring and control technology which in some cases does not meet portability or detection limit requirements. Without new technology, the curtailment of missions, closing of facilities, and assessment of fines are real possibilities.

For the liquids subthrust, the CWA requirements prohibit the discharge of untreated sewage (blackwater) by ships in navigable waters. Shipboard graywater is the product of hotel and commissary-type activities aboard U.S. Navy ships. Common sources of graywater are showers, sinks, and galley and scullery

equipment. No graywater holding capacity has been required for U.S. Navy ships with the exception of operations within the Great Lakes. However, with anticipated tightening of global wastewater discharge regulations, DoD must develop technologies that are appropriate to control and treat combined shipboard graywater and blackwater (i.e., non-oily wastewater).

Within the solids subthrust, the environmentally-safe disposal of the huge stockpile of munitions and propellants accumulated by all parties during the Cold War continues to present a substantial challenge worldwide. More than 60 percent of these materials are not amenable to disposal by disassembly, recycling, or incineration. Therefore, disposal by OB/OD has been one of the only means available. OB/OD is a relatively simple and cost effective method for stockpile reduction, but it can generate excessive air pollutants. Concerns about the short- and long-term impacts of OB/OD activities on the health of humans and ecosystems have restricted severely, and sometimes prohibited, OB/OD in the U.S. and many other countries. FY98 was the last year that SERDP initiated R&D in this area as a result of the establishment of the DoD Conventional Munitions Demilitarization Office. Two ongoing projects in this area continued in FY99. In addition to waste energetics, DoD must meet international environmental regulations limiting the disposal of solid waste and plastics at sea. To address this need, the Navy must develop compact, efficient equipment for the destruction of solid waste and sludges from waste water onboard DoD vessels.

For FY99, SERDP supported a total of 17 Compliance projects. Nine of these projects address air emissions, reflecting the emphasis to respond to existing clean air regulations and the anticipated CAAA requirements for VOCs, NOx, and PM less than 2.5 microns in diameter. Of the 9 projects in the air subthrust, 6 are developing emissions treatment/reduction technologies and 3 are developing measuring and monitoring technologies. The 4 projects in the liquids subthrust and the 3 projects in the solids subthrust are developing treatment/reduction technologies for shipboard solid and liquid wastes and for waste energetic materials.

The DoD recently issued a proposed Range Rule to respond in part to EPA's Munitions Rule, both of which require technology to address waste energetics and residues found on DoD testing and training facilities. During FY99, the SERDP Compliance Thrust Area solicited proposals and approved FY 2000 New Start projects that will focus on: 1) the fate and transport analyses of energetic materials in the environment and 2) the fate and transport of copper and zinc from DoD sources in harbors and estuaries. Two new start projects addressing these needs were selected for SERDP funding in FY 2000. The first will develop source terms that will identify and characterize the potential for the release of contaminants to soils and groundwater from energetics residues found on training/testing lands. A second project will develop a source term to identify and characterize contaminants in air emissions released by the firing and detonation of munitions and other energetic materials.

The proposed rule for Phase I of Uniform National Discharge Standards (UNDS) describes discharges that are incidental to the normal operation of DoD's vessels and identifies which of these discharges DoD will be required to control. Integral to the further development of UNDS is the need to better understand the fate and impact of metal contaminants released from vessels, such as copper and zinc released from anti-fouling coatings on ship hulls. SERDP's funding of three projects in FY 2000 will identify the fate, speciation, and distribution of copper and zinc in an effort to advance scientific knowledge of the fate and impact of copper and zinc from DoD sources in harbors and estuaries. This will help to develop a scientific basis for the development of standards for emissions of copper and zinc.

Leveraging with other Defense science and technology programs and industry, the Compliance Technology Thrust Area focuses on the following research and development objectives:

- Develop control, treatment, and disposal technologies for ship operations (bilge, grey/black wastewater, solid waste, and air emissions);

- Develop new control, treatment, and disposal technologies for hazardous wastes resulting from manufacturing, maintenance and industrial operations, and installation support operations (wastewater, solid waste, and air emissions);

- Develop control and monitoring techniques for air toxic emissions to include development and testing of models to predict emissions of, and exposures to, pollutants from Defense facilities, and to design effective, multimedia environmental management strategies;
- Develop improved monitoring, characterization, and assessment tools related to environmental compliance and management; and

- Develop standardized risk assessment methods, protocols, models, and data for air and wastewater discharges related to defense activities.

## Compliance Program

The following list reflects FY 1999 completed projects and projects continuing into FY 2000. Also included are titles of projects that begin in FY 2000. Complete descriptions of all of the projects for FY 1999 and FY 2000 may be found on the pages referenced in Appendix B - Compliance Project Summaries.

### Subthrust 1 - *Air*

Page

**FY 1999 Completed Projects**

Development of Non-Thermal Plasma Reactor Technology for Control of Atmospheric Emissions .......... B-4
Development and Integration of Laser-Based Sensors for VOC/NOx and Metals Emissions Monitoring .......... B-5
Membrane-Mediated Extraction and Biotreatment of VOCs .......... B-16

**FY 2000 Continuing Projects**

Detect and Identify Multiple Hazardous Air Pollutants (HAP) at Extended Distances ...... B-7
Plasma-Assisted Catalytic Reduction of NOx .......... B-9
Optimization of an Innovative Biofiltration System as a VOC Control Technology for Aircraft Painting Facilities .......... B-14
Characterization of Particulate Emission: Size Characterization and Chemical Speciation B-17
Development of a Catalyzed Ceramic Filter for Combined $PM_{2.5}$ Removal and VOC and CO Oxidation .......... B-22
Reduction of Particulate Emissions from Jet Engine Test Cells Using an Annular After-Reactor .......... B-24

**FY 2000 New Start Projects**

A Predictive Capability for the Source Terms of Residual Energetic Materials from Burning and/or Detonation Activities .......... B-34

### Subthrust 2 - *Liquids*

**FY 1999 Completed Projects**

Kinetics of Supercritical Water Oxidation .......... B-2

**FY 2000 Continuing Projects**

Electrochemical Advanced Oxidation Process for Shipboard Final Purification of

Filtered Black Water, Gray Water, and Bilge Water . . . . . . . . . . B-19
Novel Nonporous Fouling - Resistant Composite Nanofiltration Membranes and Membrane Separation Systems for Wastewater Treatment . . . . . . . . . . B-21
Purification of Oily Wastewaters by a One-Step Advanced Biodegradation Precess that Produces No Secondary Wastestreams . . . . . . . . . . B-27

**FY 2000 New Start Projects**
Determining the Fate and Ecological Effects of Copper and Zinc Loading in Estuarine Environments: A Multidisciplinary Approach . . . . . . . . . . B-31
Speciation, Fluxes, and Cycling of Dissolved Copper and Zinc in Estuaries: The Roles of Sediment Exchange and Photochemical Effects . . . . . . . . . . B-32
Speciation, Sources, and Bioavailability of Copper and Zinc in DoD-Impacted Harbors and Estuaries . . . . . . . . . . B-33
Use of a Nafion Membrane Probe for Quick, On-the-Spot Determination of Ionic Copper Contamination Levels in Natural Waters *(SEED project)* . . . . . . . . . . B-35

## Subthrust 3 - *Solids*

**FY 1999 Completed Projects**
Enzymes for Degradation of Energetic Materials and Demilitarization of Explosives Stockpiles . . . . . . . . . . B-11

**FY 2000 Continuing Projects**
Hypergolic Non-Detonative Neutralization in Production and Demilitarization . . . . . . . . . . B-13
Thermal Actively Controlled Sludge Treatment . . . . . . . . . . B-25

**FY 2000 New Start Projects**
Distribution and Fate of Energetics on DoD Test and Training Ranges . . . . . . . . . . B-29

## Other

**FY 1999 Completed Projects**
National Environmental Education and Training Center (NEETC) . . . . . . . . . . B-3

# FY 2001 Compliance Initiatives

FY 2001 Compliance Initiatives will respond to recently finalized as well as anticipated regulatory developments related to DoD air emissions, non-point source runoff to surface waters from DoD lands, and clearing of range residue and scrap from testing and training activities on DoD installations.

Regulatory requirements associated with DoD air emissions continue to be a major research priority in the Compliance Thrust Area. An Executive Order for Federal Facilities regarding the Emergency Planning and Community Right-to-Know Act (EPCRA) Toxic Release Inventory (TRI) Reporting currently is being evaluated by DoD to determine which of DoD's activities will be subject to TRI reporting requirements. To proactively respond to these requirements, SERDP has issued an SON for FY 2001 entitled **Measuring, Characterizing, and Control of Toxic Release Inventory Air Emissions from DoD Munitions**. The focus of this SON is to identify, characterize, and develop innovative and cost-effective technologies for control of TRI air emissions from munitions at testing and training ranges on DoD installations and aboard Navy and Coast Guard vessels.

A second SON was issued for FY 2001 to respond to another upcoming requirement for DoD air emissions, the Regional Haze Rule. The Regional Haze Rule, which evolved from the 1977 amendments to the CAA, established a national visibility goal to prevent visibility impairment in large national parks and wilderness areas. The visibility impairment is caused by particles in the atmosphere such as soot, smoke, dust, carbon, primary gases that absorb light, such as nitrogen oxide, and secondary particles formed by gaseous and hydrocarbon emissions, including sulfur dioxide, and nitrates. DoD training and testing activities at installations across the U.S. often involve the movement of vehicles and personnel on unpaved surfaces, prescribed burning to clear brush and unwanted vegetation, as well as the use of smokes and obscurants for battlefield operations. The proximity of installations engaged in training and testing activities to Class I Federal areas raises a concern about the impact of the Regional Haze Rule on military training and readiness. The objective of research under the SON **Training/Testing Range Dust Emissions Characterization** will be to identify, characterize, and monitor the airborne emissions resulting from DoD testing/training activities. This SON will respond to revisions to the National Ambient Air Quality Standards (NAAQS) for ozone and particulate matter and proposed regulations to address the impairment of long distance outdoor visibility resulting from regional haze.

Amendments to the Clean Water Act and the Uniform National Discharge Standards were identified as important drivers for formulating a third core SON for FY 2001, **Measuring, Monitoring, And Managing Non-Point Source Runoff at Military Installations**. The objective of this SON is to solicit proposals to develop innovative and cost-effective technologies to identify, characterize, and monitor non-point source runoff at DoD installations. Research is needed under this SON to: 1) develop technologies to identify and prioritize potential non-point runoff sources and potentially impacted surface water bodies at DoD installations; 2) develop field-portable technologies to provide real-time monitoring of the volume and characterization of non-point source runoff from DoD installations; 3) develop innovative and cost-effective treatment and/or control technologies, including erosion control, runoff detention, sediment management, and oily water treatment to mitigate the impacts of non-point source runoff that are unique to military installations; and 4) advance the state-of-knowledge of the development of total maximum daily limits (TMDL) to quantify and model the contribution of DoD sources of non-point pollution to watersheds in which they are located.

In addition to the core Compliance SONs discussed above, SERDP has solicited proposals to respond to one SEED SON, **Analysis, Characterization, and Treatment of Energetic Residues on Scrap Materials at Military Training/Testing Installations**. In this SEED SON, SERDP intends to fund research to develop innovative and cost-effective technologies to analyze, characterize, and treat energetics residues on scrap materials found on training/testing ranges at DoD installations. Results from this research should: 1) improve the ability to analyze and characterize the energetics residues found on the wide variety of scrap materials (exclusive of unexploded ordnance) and 2) develop new, innovative, and cost effective technologies to effectively treat energetics residues found on scrap materials to render them non-hazardous and suitable for recycling/recovery. The expected payoff of this research is the ability to safely and completely remove energetic materials to ensure the safe recycling of range scrap. The clearing of the residues will allow testing/training ranges areas to be reused for additional training where reentry by combat troops is necessary in order to obtain realistic training.

Detailed descriptions of the FY 2001 Compliance Statements of Need may be found in Appendix E.

# CONSERVATION

## Introduction

To continue to train and test military capabilities in a realistic and safe manner, DoD must maintain the nation's natural and cultural resources of the installations upon which it depends. It also must comply with

legislation and regulations designed to protect these resources. DoD's challenge is to balance the use of air, land, and water resources for current military readiness with the need to protect and manage these resources for all desired long-term uses.

The DoD Conservation goal is to support the military mission by (1) providing for sustained use of its land, sea, and air resources; (2) protecting valuable natural and cultural resources for future generations; (3) meeting all legal requirements; and (4) promoting compatible multiple uses of those resources. Knowledgeable, proactive management of natural resources and cultural resources is critical because the natural environment provides the realistic training environment in which to exercise and test the capabilities of the military forces. Several Federal statutes such as the Endangered Species Act (ESA); the National Environmental Policy Act (NEPA); the Sikes Act; the Migratory Bird Treaty Act; the Fish and Wildlife Coordination Act; the Marine Mammal Protection Act (MMPA); the National Historical Preservation Act (NHPA); the Historical and Archaeological Data Preservation Act; the Native American Grave Protection and Repatriation Act (NAGPRA); the American Indian Religious Freedom Act; the Flood Disaster Protection Act; and local laws, regulations, and requirements provide specific stewardship direction for all DoD and DOE lands. Other Conservation requirements include The American Heritage Rivers Initiative and four Conservation Presidential Memorandums involving Recreational Fisheries, Indian Sacred Sites, Floodplain Management, and Protection of Wetlands, which further implement and support the above mentioned Federal statutes.

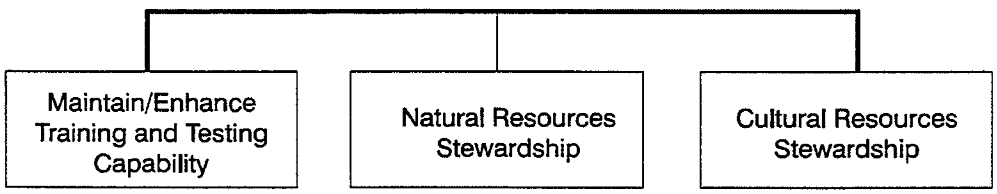
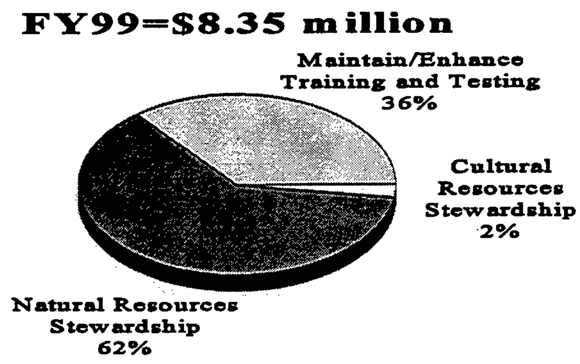



**Figure III-6. Conservation Taxonomy**

DoD and DOE must be effective and proactive stewards of natural and cultural resources under their direction. By better understanding the environments in which they operate, the Departments can improve their resource-use decisions to promote conservation and stewardship, while continuing to fulfill their primary missions. DoD's Conservation concerns, as depicted in Figure III-6, can be divided into three distinct operating areas in which the Department conducts training and testing and, therefore, impacts the natural environment, including air, land, and water (oceans and waterways).

| CONSERVATION | |
|---|---|
| **FY 1999** | |
| 15 | Total projects |
| 3 | Completed projects |
| 2 | New Start projects |
| **FY 2000** | |
| 20 | Total projects |
| 7 | Completing projects |
| 8 | New Start projects |

Figure III-7 shows the funding by subthrust area. For FY 1999, Conservation received approximately 14 percent of the SERDP budget. In future years, Conservation funding will gradually increase as a percentage of the SERDP funding to support a more sustainable future.



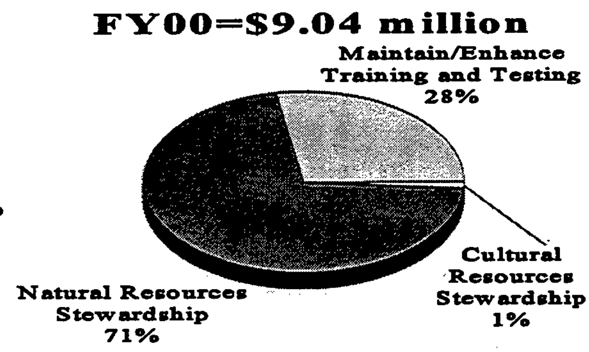




**Figure III-7. SERDP Conservation Funding by Subthrust, FY 1999 – FY 2000**
NOTE: FY99 values represent actual funding. FY00 values are planning figures based upon the President's Budget Request.

## Principal Driving Requirements

Each uniformed Service has submitted its User Requirements for Conservation, which are prioritized in the DoD Environmental Technology Requirements Strategy. These individual requirements affect all operating environments and can be grouped into three related but distinct principal driving requirements for DoD:

- To maintain and enhance its training and testing capability to ensure military readiness;
- To steward and protect the natural resources under its control; and
- To steward and protect the cultural resources under its control.

The Department of Defense is a major user of land, sea, and air, managing 25 million acres of land on more than 425 major military installations, and it is the third largest Federal land management department in the United States. DoD requires continued access to these lands, waterways, and airspace to maintain mission readiness. Land is needed for munitions testing, deployment of weapon systems, and combat training exercises. Marine and estuarine environments are needed to conduct training exercises, test vessels and submarine tracking equipment, evaluate missile weapon systems, and conduct shock trials on new ships. Airspace is needed to train pilots and test fighter planes and air-based weapon systems. The specific landscapes and unique natural features of the land, sea, and air space used by DoD are crucial to military readiness. Varied training regimens and differing climatic, topographic, hydrologic, and biological settings prepare troops to operate equipment and carry out operational plans under conditions they may encounter in future conflicts.

With a broad geographic distribution (largely domestic but some foreign), DoD lands represent a remarkably diverse collection of ecosystem and habitat types, including forests, grasslands, wetlands, and deserts. DoD's ability to conduct realistic training exercises and to test weapon systems and equipment cannot be ensured without responsible land stewardship and sensible management and conservation practices. One half of the Army's training ranges, for example, are under some level of environmental restriction and must be managed appropriately.

The Departments of Defense and Energy lands are subjected to a wide variety of uses ranging from military training to hazardous waste disposal to timber production. Nevertheless, these lands are often the last large natural areas in otherwise developed environments. As such, they represent valuable resources for preserving the biodiversity of their local regions, and they serve as refuges for a wide variety of threatened and endangered species. Nearly 1,000 species in the U.S. are protected under the ESA, while thousands more are candidates for listing. More than 200 installations provide habitat for at least 400 plants and animals that are listed on, or are candidates for, the Federal endangered species list. This is the highest known density

of threatened and endangered species found on any Federal lands. DoD installations contain some of the finest remaining examples of such rare native vegetative communities as old-growth forests, tall-grass prairies, and vernal pool wetlands. This can lead to mission constraints and impediments to land acquisition, potentially leading to reduced defense readiness, lengthy and costly litigation, and, sometimes, criminal and civil penalties. DoD's ability to address this issue is limited because of inadequate information on the distribution and abundance of threatened and endangered species (TES) and their habitats on military land, the effects of mission activities on TES and supporting ecosystems, and appropriate mitigation and management options.

Furthermore, military facilities face increasing demands as a result of base closures and realignments, new weapon systems and equipment requiring larger training ranges, additional regulatory constraints, and changes in tactics and doctrine. Training intensity on remaining installations will continue to rise, often preventing full recovery of vegetation between training exercises. The U.S. Army alone has 11 million acres of training and testing lands with land repair and maintenance costs of $56 million annually. On-site and off-site environmental impacts, wildlife conservation issues, cultural resources concerns, and the need for training realism all dictate that natural resources must be maintained and enhanced on these installations. The tasks of balancing military land uses, complying with resource regulations, and assessing impacts on the sustainability of both the resource base and the military mission are complex and challenging. Activities to alleviate one problem can often exacerbate others. All too often, decision-makers on military installations are faced with making critical land management decisions without the benefit of complete environmental information nor complete knowledge of other, competing objectives and/or land use requirements.In the Water Operating Environment, the Navy must comply with the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA), and the Marine Mammal Protection Act (MMPA) in all operations and tests. This is a difficult task when "take" is defined under the MMPA to mean "harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal."

In the Air Operating Environment, the Air Force is required to assess the impacts of proposed aircraft operations on the environment. Many of the assessments accomplished to date contain unsubstantiated, anecdotal remarks concerning the effects of aircraft noise on wildlife. Quantitative data are needed for environmental planners at the major command and staff levels to defend the Air Force's, Navy's and Marine Corps'low altitude Military Training Routes (MTR), which are essential for combat training. The U.S. Fish and Wildlife Service can and has stopped many proposed low altitude flight activities through the use of formal Section 7 consultations in accordance with the Endangered Species Act.

The current reliability associated with the detection and location of cultural and archeological artifacts is minimal. Once a cultural or archeological resource site is identified, it must then be assessed in order to determine its significance. Currently, the costs associated with Phase II assessments of cultural and archeological resources are quite high. In the Army alone, there are approximately 100,000 archeological sites, and at least 200 installations have properties that are listed on or eligible for the National Register of Historic Places. In addition, DoD must comply with the requirements of NAGPRA, which protects Native American artifacts and cultural items, and the Archeological and Historic Preservation Act, which requires evaluation of proposed activities on the cultural environment. New techniques and capabilities are needed to reduce the costs of compliance and to avoid delays and the possibility of damaging artifacts when an unanticipated but significant discovery occurs at a construction site.

In an effort to develop a more long-term and integrative approach to its resource management (i.e., land, waterways, airspace), DoD remains committed to an ecosystem-oriented management perspective. Installations in all of the Services conduct active ecosystem management programs, supporting both the sustainable mission use of military resources and stewardship of these resources. All of the DoD services have expressed (in formal research requirements and through other mechanisms) the need to better understand ecological processes and trends on military lands, the ecological relationship of military lands to their surrounding lands, and the interactions between mission activities and ecological processes.

In response to these expressed needs, SERDP developed an initiative that focuses on addressing science and technology requirements for ecosystem management of DoD military installations. This project, entitled the SERDP Ecosystem Management Program (SEMP) (CS-1114), is currently hosted at Ft. Benning, GA (web site: http://www.denix.osd.mil/SEMP). Ft. Benning is situated in southwestern Georgia, just below the Piedmont/Southeast Coastal Plain Fall Line, along the sand hills region that extends from Alabama into North Carolina. The major components of SEMP are (1) the creation of long term monitoring site(s) on DoD lands to observe ecosystem trends over time, and (2) the establishment of research projects aimed at gaining a better understanding of the roles of DoD military mission activities and land management practices at various spatial and temporal scales. The goals of SEMP are to provide knowledge, tools, and techniques to enhance sustainable mission use and stewardship of military installations and to contribute to understanding and enhancing the ecological role of military installations within their ecoregions.

Leveraging with other Defense science and technology programs and similar programs in industry and academia, SERDP focuses on the following Conservation research and development objectives:

- Develop standardized, cost effective methods to inventory, characterize, and monitor natural and cultural resources to help ensure compliance with applicable laws and requirements. Where appropriate, use defense-unique data collection and assessment tools to develop these methods;

- Develop and demonstrate more effective methods and techniques to maximize availability of military lands in support of military missions, with minimal impact to natural and cultural resources in a manner consistent with the Services' mission and Federal environmental regulations;

- Develop and demonstrate efficient and effective techniques to conserve and restore natural and cultural resources proactively, particularly threatened and endangered species and the ecosystems on which they depend;

- Develop and demonstrate effective, user-friendly computer-based models to determine the incremental and cumulative impact of military activities on natural and cultural resources, and assess effectiveness of conservation and restoration techniques;

- Develop state-of-the-art techniques to assess and predict the impact of military use on those critical elements of the ecosystem impacting biodiversity; and

- Develop the needed methods, tools, guidelines, and decision support systems for effectively implementing integrated resource management techniques.

## Conservation Program

The following lists reflect FY 1999 completed projects and projects continuing into FY 2000. Also included are titles of projects commencing in FY 2000. Complete descriptions of all of the projects for FY 1999 and FY 2000 may be found on the pages referenced in Appendix C - Conservation Project Summaries.

### Subthrust 1 - *Maintain/Enhance Training & Testing Capability*

Page

**FY 1999 Completed Projects**

None

**FY 2000 Continuing Projects**

Development and Demonstration of a Risk Assessment Framework for Natural Resources on Military Training and Testing Lands .......... C-4
Information Technology Tools for Assessment and Prediction of the Potential Effects of Military Noise on Marine Mammals .......... C-7
Assessment of Training Noise Impacts on the Red-Cockaded Woodpecker .......... C-8
Improved Units of Measure for Training and Testing Area Carrying Capacity Estimation . C-15
Identify Resilient Plant Characteristics and Develop a Wear Resistant Plant Cultivar for Use on Military Training Lands .......... C-17
Diagnostic Tools and Reclamation Technology for Mitigation Impacts of DoD/DOE Activities on Arid Areas .......... C-21

**FY 2000 New Start Projects**

None

## Subthrust 2 - *Natural Resources Stewardship*

**FY 1999 Completed Projects**

Threatened, Endangered, and Sensitive Resources .......... C-2
Advanced Biotelemetry for Resource Management .......... C-3

**FY 2000 Continuing Projects**

Analysis and Assessment of Military and Non-Military Impacts on Biodiversity: Framework for Environmental Management on DoD Lands Using Mojave Desert as a Regional Case Study .......... C-5
Error and Uncertainty Analysis for Ecological Modeling and Simulation .......... C-9
Ecological Modeling and Simulation Using Error and Uncertainty Analysis .......... C-10
Emerging and Contemporary Technologies in Remote Sensing for Ecosystem Assessment and Change Detection on Military Reservations .......... C-11
Predicting the Effects of Ecosystem Fragmentation and Restoration: Management Models for Animal Populations .......... C-13
SERDP Ecosystem Management Program .......... C-18

**FY 2000 New Start Projects**

Application of Hyperspectral Techniques to Monitoring & Management of Invasive Weed Infestation .......... C-24
Exotic Annual Grasses in Western Rangelands: Predicting Resistance & Resilience of Native Ecosystems Invasion .......... C-26
Integrated Control & Assessment of Knapweed & Cheatgrass on DoD installations .......... C-27
Developing Biological Control of Garlic Mustard .......... C-29
Analysis of Desert Shrubs Along 1st Order Channels on the Desert Piedmonts: Possible Indicators of Ecosystem Health & Historic Variation (*SEED project*) ... C-30
Measures of Ecological Integrity for Salmonid Streams in the Pacific Northwest (*SEED project*) .......... C-31
Feasibility Study: Lab-on-a-Chip & In-Situ Bioassay Techniques for Rapid Resolution of Ion Signatures for Disturbances of Bio Significance in Streams (*SEED project*) .. C-33

## Subthrust 3 - *Cultural Resources Stewardship*

**FY 1999 Completed Projects**

Direct Detection of Archeological Sites Using Remote Sensing .......... C-23

**FY 2000 Continuing Projects**

None

**FY 2000 New Start Projects**

Dynamic Modeling of Military Training Impacts and Archaeological Site Distributions in Evolving Landscapes . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . C-20

## FY 2001 Conservation Initiatives

The FY 2001 initiatives reflect an identified need to provide more opportunities for advance research efforts to address DoD's needs in the areas of natural and cultural resource stewardship. Currently, the SERDP is supporting mostly basic and applied research efforts in the Conservation Thrust Area. Therefore, the FY 2001 initiatives are attempting to address advance research issues by broadening the areas of possible work. Also, as the SERDP Conservation thrust area broadens its scope of research, it will take a more proactive role in working with the DUSD(ES) Legacy Program in transitioning the research through demonstrations in order that the information can be utilized by base environmental personnel to protect the environment while training is being conducted.

For FY 2001, there are two new initiatives in Conservation's Maintain/Enhance Training and Testing subthrust area and two new initiatives in the Natural Resource Stewardship subthrust area. In order to advance future initiatives in the Cultural Resource Stewardship subthrust area, SERDP, in collaboration with DoD's Legacy Program, is sponsoring a cultural resource management workshop in June of 2000. This workshop will provide the foundation to define future initiatives that focus on cultural resource management issues.

One FY 2001 initiative in the Maintain/Enhance Training and Testing subthrust area is entitled **Advanced Techniques to Inventory and Monitor Threatened and Endangered Species in Inaccessible Areas.** This initiative is searching for initial or applied development of advanced techniques to inventory and monitor wildlife populations, including threatened and endangered species (TES), in inaccessible areas (i.e., firing ranges and impact areas on military installations). Due to the potential risk to human health and safety specific to unexploded ordnance (UXO), the advanced techniques will require some sort of standoff sensing technique(s), e.g. listening devices, imagery, and/or other methods, combined with the appropriate tools to spatially analyze and display results. The proposed efforts need to be complementary with, or suitable for use with, standard data analysis and assessment techniques used in restricted access and inaccessible areas so installations can use the information for reporting the total installation's occurrence, population, impacts, and trends.

**Marine Mammal Monitoring** is the second initiative in the Test and Training subthrust area. This initiative addresses: (1) the development of a general monitoring capability for selected ocean areas to determine the location, abundance and behavior of marine mammals prior to, during and after a Defense activity, and (2) identification of short-term and long-term impact of Defense activities on marine mammals. The objective is to determine the feasibility of monitoring the behavior of, and measuring the near- and long-term effects of various Navy and Defense tests, sonar system evaluations, and ocean experiments on marine mammals in regional ocean areas. The initiative is soliciting innovative proposals addressing monitoring techniques, sensor and data processing methods, and assessments and correlation studies.

The FY 2001 initiative in the Natural Resource Stewardship subthrust is **Riparian Ecosystem Management and Restoration**. The objective of this initiative is twofold: (1) to evaluate the environmental impacts of military land use activities on riparian ecosystems, and (2) to develop restoration/enhancement methods and conservation management techniques to minimize these impacts and sustain the beneficial services provided by riparian ecosystems on DoD installations. The expectation is to receive proposals in the following areas: field studies, management strategies, and/or new, or an enhancement of an existing, restoration technique.

A FY 2001 SEED initiative under the Natural Resource Stewardship subthrust, **Unique Indicators of Stress on Threatened and Endangered Species,** will identify unique, non-invasive indicators of stress or impact of military activities on TES. The indicators must be capable of rapidly and economically yielding thresholds of risk to TES from military impacts. It is important that a proposed indicator be able to be assessed in an accurate and efficient manner that can be replicated for monitoring purposes at locations where target TES might be located. Proposed techniques must be suitable for incorporation into standard protocols for analysis and assessment of TES, and be applied to a range of military stresses.

Detailed descriptions of the FY 2001 Conservation Statements of Need may be found in Appendix E.

# POLLUTION PREVENTION

## Introduction

The Pollution Prevention Technology Thrust Area focuses on reducing or eliminating the generation of pollution within the DoD. The application of pollution prevention technologies will influence positively the other DoD environmental Thrust Areas by encouraging the use of innovative technologies and practices such as recycle, recovery and reuse, reducing pollutants to be managed at the source, and promoting the sustainable use of natural resources.

As defined under the Pollution Prevention Act of 1990, pollution prevention means "source reduction" and other practices that reduce or eliminate the creation of pollutants through increased efficiency in the use of raw materials. Source reduction is defined as any practice that reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal. SERDP Pollution Prevention does address end-of-pipe recycling of wastes for originally designed uses, such as the recycling of munitions and their materials back into the production of new munitions.

The DoD and DOE have a number of unique functions, such as the development and operation of sophisticated weapons systems which demand specialized, high-performance materials. Many of these materials are toxic and are targeted for voluntary reduction. The challenge to DoD and DOE is sustainability, which translates to finding new high-performance materials that are not toxic and/or to determine innovative ways to control the use of toxic chemicals in order to reduce releases and off-site transfers.

Waste minimization programs in the private sector have demonstrated that pollution prevention saves money. Addressing those pollution prevention technology needs which are not adequately addressed by the private sector will be the focus for DoD and DOE in order to meet their environmental obligations in a cost effective manner. Material substitutions, manufacturing process changes, inventory and stockpile controls, and adjustments to routine daily processes will be required to meet these obligations.

The Pollution Prevention Thrust Area, at the recommendation of the SERDP Scientific Advisory Board, is adopting a proactive approach to provide solutions to the highest priority defense- related environmental problems. The Pollution Prevention Thrust Area, in addition to addressing near term multi-service DoD problems, also will address more forward looking, high-risk, long- term projects to achieve the goals that will be set forth by future regulations. For example, the development of the next generation of environmentally advantaged DoD systems is key to meeting potential future regulations. This will be done by designing tools to alert planners to potential environmental issues. SERDP will work closely with military planners, Service research organizations, and the Office of Deputy Under Secretary of Defense for Environmental Security to identify long-term needs for the Department.

The Pollution Prevention Technical Thrust Area Working Group (TTAWG) recommended a shift in program emphasis within the pollution prevention pillar. The TTAWG indicated that the role of the Services should be to identify and address the compliance issues within their respective Services and that SERDP should focus its resources on addressing the more global, tri-Service issues and on developing seed technologies to address emerging regulatory issues. The TTAWG also envisioned SERDP's role as a facilitator in communication and collaboration to enhance technology transfer and to leverage Service and SERDP resources. This will be accomplished through increased interaction with the National Defense Center for Environmental Excellence (NDCEE), the National Center for Manufacturing Sciences (NCMS), and participation in Joint Acquisition Sustainment Pollution Prevention Activities (JASPPA) initiatives.

SERDP continues to use topical workshops as a tool to identify DoD/DOE user needs, to better understand the existing state-of-the-art technology in these areas, and to identify environmentally driven requirements and any industry or DoD initiatives addressing them. In addition to fostering technology transfer, this information is used to help focus the SERDP program on the highest priority issues and to avoid duplication of effort. A joint Pollution Prevention/Compliance workshop on air emissions issues associated with Gas Turbine Engines, Diesel Engines, and Energetics was held in June 1999. Some of the recommendations resulting from these workshops will form the basis for new start projects in the SERDP FY 01 program. Additionally, starting FY00, the pollution prevention program will focus on systems approach to address DoD user needs and will continue to work on the next generation of concepts/materials. An example would be the increased use of Composites in DoD systems.

The Air Force, Army, and Navy have each submitted their Pollution Prevention User Requirements, which are prioritized in the DoD Environmental Technology Requirements Strategy (DETRS). These requirements can be grouped into specific environmental concerns. The primary DoD environmental concerns in Pollution Prevention are:

- Identifying alternatives for hazardous and toxic chemicals and materials;
- Reducing the use of hazardous and toxic chemicals and materials;
- Reducing the volume and toxicity of wastes and pollutants through source reduction;
- Improving the efficiencies of mechanical and chemical systems;
- Incorporating environmental ramifications as key evaluation considerations in major system design and acquisition;
- Considering the life-cycle effects of materials and systems; and
- Evaluating the sustainable use of resources.

These DoD Pollution Prevention needs are addressed by the four major sub-thrust areas of Air, Water, Solids, and Modeling and Measurements, which are further organized as shown in Figure III-8.

The FY 1999 and FY 2000 distribution of SERDP funding for Pollution Prevention among the subthrust areas is shown in Figure III-9. For FY 1999, Pollution Prevention received approximately 27 percent of the SERDP budget. In the out years, Pollution Prevention will continue to grow relative to the three other technology areas of SERDP in order to meet DoD users' demands for better, cheaper, and cleaner weapons systems and processes.

**POLLUTION PREVENTION**

| FY 1999 | |
|---|---|
| 24 | Total projects |
| 5 | Completed projects |
| 9 | New Start projects |

| FY 2000 | |
|---|---|
| 24 | Total projects |
| 6 | Completing projects |
| 5 | New Start projects |

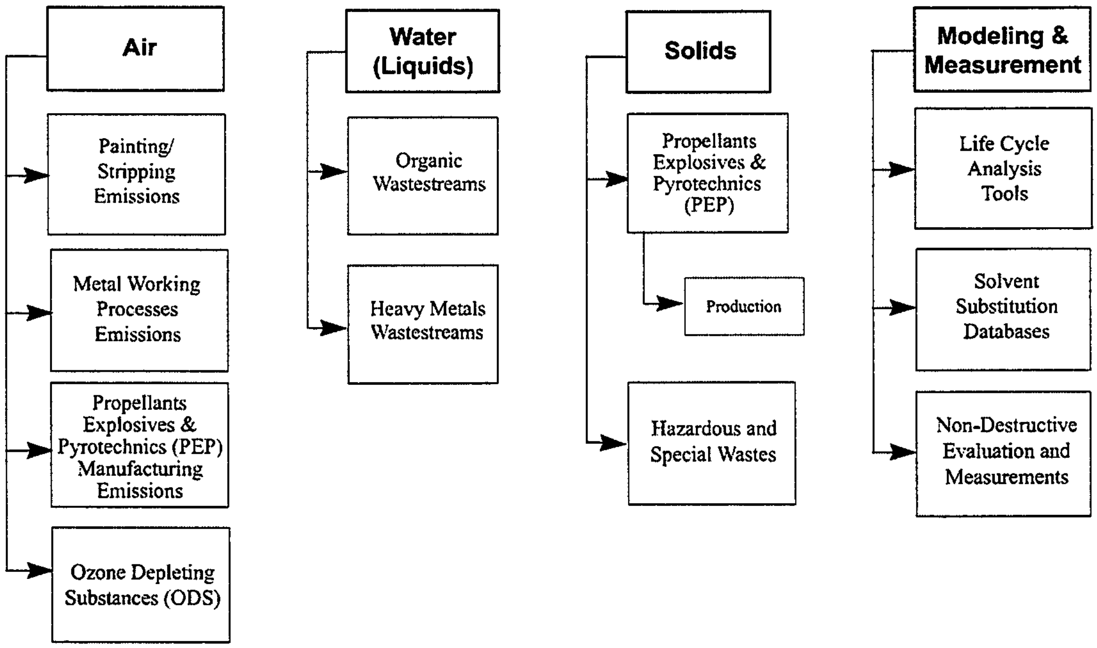



**Figure III-8. Pollution Prevention Taxonomy**

Future SERDP Pollution Prevention projects will be selected based on the following general metrics:

- Expected payoff (i.e., potential cost avoidance);
- Magnitude of the environmental problem that the technology will address;
- Clearly identifiable potential environmental benefits and impacts on the defense establishment, regardless of whether the project addresses current, near-, mid-, or long-term needs; and
- Leveraged funding from Services/Agencies is encouraged by the project.

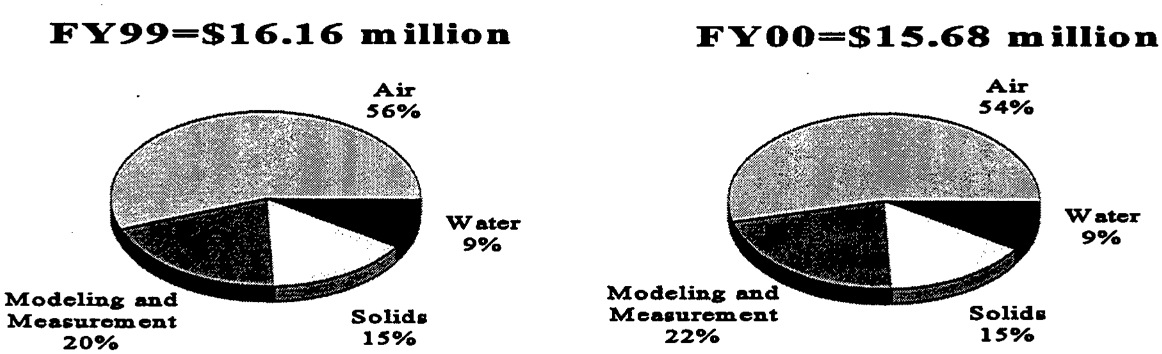



**Figure III-9. SERDP Pollution Prevention Funding by Subthrust, FY 1999 – FY 2000**

NOTE: FY99 values represent actual funding. FY00 values are planning figures based upon the President's Budget Request.

## Principal Driving Requirements

Executive Order (EO) 12856, "Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements," states that the Federal Government should become the leader in the field of Pollution Prevention through the management of its facilities, its acquisition practices, and by supporting the development of innovative pollution prevention programs and technologies. The EO challenges the heads of the DoD and DOE to set goals voluntarily to reduce their agency's total releases of toxic chemicals to the environment and off-site transfers by 50 percent from 1994 baseline figures by December 31, 1999.

Virtually all DoD maintenance and repair activities involve the use of toxic or hazardous substances. The 1990 Clean Air Act Amendments (CAAA), the Resource Conservation and Recovery Act (RCRA), and state and local regulations restrict the emission and disposal of these hazardous materials. Ozone depleting substances (ODS) are being phased out of production under national policy and international (Montreal) protocol. DoD directives require significant reductions in hazardous wastes and development of alternative materials and processes that meet environmental restrictions and allow DoD to continue operations. Operations and training activities at DoD installations and facilities generate large quantities of hazardous, non-hazardous, and special wastes that are expensive to manage and dispose.

During this decade, an increasing emphasis has been placed on pollution prevention to reduce environmental impacts associated with DoD weapon systems acquisition. The DoD Pollution Prevention Strategy of August 11, 1994, established a goal to identify and develop environmental life cycle cost estimating tools that inject pollution prevention and other environmental concerns into acquisition decisions. Development and application of modeling and simulation tools to identify and test technical solutions that reduce reliance on toxic materials and processes are required.

On September 14, 1998, EO 13101, "Greening the Government Through Waste Prevention, Recycling, and Federal Acquisition," was signed by the President. The new EO is designed to further expand and strengthen the Federal government's commitment to recycling and buying recycled content and environmentally preferable products, (including biobased products). Under this EO, Federal agencies will establish specific goals for (1) waste prevention and recycling or solid waste diversion, (2) affirmative procurement of products that are made with recovered materials, and (3) procurement of environmentally preferable products and services for which a pilot project has been successfully completed. Agencies will annually evaluate their progress toward attaining these goals. In addition to EO 13101, two other new Executive Orders, namely EO 13123 - "Greening the Government through Efficient Energy Management," and EO 13134 - "Bio Based Products and Bioenergy," were signed by the President on June 3, 1999, and August 12, 1999 respectively. These two EOs will also guide the development of the SERDP Pollution Prevention program for the outyears.

Leveraging with other DoD, DOE, and EPA science and technology programs and industry, the Pollution Prevention subthrust areas focus on the following research and development objectives:

- Alternative materials and processes to replace defense uses of hazardous heavy metals (e.g., chromium, cadmium, lead, nickel) and metallic compounds and hazardous air pollutants;
- Alternatives to VOC-containing coatings, adhesives, sealants, and lubricants that are not being addressed adequately by industry;
- Alternatives to hazardous and toxic chemicals for surface cleaning, degreasing, and paint stripping;
- Alternatives to hazardous and toxic chemicals, especially ODS, used in climate control, refrigeration, solvents, and fire-fighting agents;

- Techniques to regenerate, recycle, re-use, and stockpile defense unique toxic chemicals and materials;
- On-line sensors and monitoring systems to prolong usefulness of toxic chemicals in defense operations such as plating, stripping, and mechanical maintenance;
- Cost-effective, environmentally preferable packaging and recycling approaches to reduce generation of solid waste from defense-related operations; and
- Predictive models (which include environmental life cycle costing) to aid in the development of environmentally sound weapon systems and platforms during concept development, design, test and evaluation, maintenance (logistics support documentation), and decommissioning.

## Pollution Prevention Program

The following list reflects FY 1999 completed projects and projects continuing into FY 2000. Also included are titles of projects commencing in FY 2000. Complete descriptions of all of the projects for FY 1999 and FY 2000 may be found on the pages referenced in Appendix D - Pollution Prevention Project Summaries.

### Subthrust 1 - *Air*

Page

**FY 1999 Completed Projects**

Solventless Manufacture of Artillery Propellant Using Thermoplastic Elastomer Binder .......... D-3
Low VOC Chemical Agent Resistant Coatings (CARC) .......... D-8

**FY 2000 Continuing Projects**

Trapped Vortex Combustor for Gas Turbine Engines .......... D-4
Elimination of Toxic Materials and Solvents from Solid Propellant Components .......... D-11
Next Generation Fire Suppression Technology Program .......... D-13
Replacement of Non-Toxic Sealants for Standard Chromated Sealants .......... D-17
Sol-Gel Technology for Low VOC, Non-Chromated Adhesive & Sealant Applications ... D-25
Primerless RTV Silicone Sealants/Adhesives .......... D-35
Non-Structural Adhesives Requiring No VOCs .......... D-40

**FY 2000 New Start Projects**

Electro-Spark Deposited Coatings for Replacement of Chrome Electroplating .......... D-42
Electrodeposited MN-SN-X Alloys for Corrosion Protection Coatings (*SEED project*) ... D-44
Clean Dry-Coating Technology for ID Chrome Replacement .......... D-45
Electroformed Nanocrystalline Coatings: An Advanced Alternative to Hard Chrome Electroplating .......... D-46

### Subthrust 2 - *Water*

**FY 1999 Completed Projects**

Recycle and Reuse of Industrial Rags Using Liquid CO2 and Surfactant Additives as a Cleaning Agent .......... D-24

**FY 2000 Continuing Projects**
Genetic Enhancement of an Anti-Freeze Protein for Use as a Substitute for Ethylene Glycol for Aircraft Deicing . . . . D-21
Environmentally Advantaged Substitutes for Ethylene Glycol for Aircraft Ice Control . . . . D-22
Supercritical Fluid Spray Application Process for Adhesives and Primers . . . . D-28

**FY 2000 New Start Projects**
None

## Subthrust 3 - *Solids*

**FY 1999 Completed Projects**
None

**FY 2000 Continuing Projects**
Eliminate Toxic and VOC Constituents from Small Caliber Ammunition . . . . D-9
Tri-Service "Green" Gun Barrel - A Physical Vapor Deposition for the Application of Environmentally Safe Coatings for Gun Barrel Bore Protection . . . . D-15
Non-Polluting Composites for Remanufacturing and Repair for Military Applications . . . . D-19

**FY 2000 New Start Projects**
None

## Subthrust 4 - *Modeling & Measurement*

**FY 1999 Completed Projects**
Recycling Propellants in Nonpolluting Supercritical Fluids: Novel Computational Chemistry Models for Predicting Effective Solvents . . . . D-2
Pesticide Reduction through Precision Targeting . . . . D-6

**FY 2000 Continuing Projects**
Visual Cleaning Performance Indicators for Cleaning Verification . . . . D-27
Critical Factors for the Transition from Chromate to Chromate Free Corrosion Protection . . . . D-30
Mechanisms of Military Coatings Degradation . . . . D-32
Development of Innovative Nondestruction Evaluation (NDE) Technologies for the Inspection of Cracking and Corrosion under Coatings . . . . D-34
Nondestructive Testing of Corrosion under Coatings . . . . D-36
Cleaning Verification Techniques Based on Infrared Optical Methods . . . . D-38

**FY 2000 New Start Projects**
Computational Design of Corrosion Resistant Steels for Structural Application (*SEED project*) . . . . D-43

# FY 2001 Pollution Prevention Initiatives

SERDP is proposing eight new start initiatives, four core statements of need (SON) and four SEED SONs. The primary focus of the FY 2001 program is to reduce overall the air emission sources from various DoD

sources, specifically the reduction of particulate matter from diesel and gas turbine engines. On the energetics front, the FY 2001 SERDP program will seek new technologies to develop environmentally friendly pyrotechnic formulations for DoD, and to reduce the use of toxics in the manufacture and maintenance of igniter or primer materials for DoD applications. The pollution prevention program will also seek out and develop new technologies for environmentally friendly new materials such as composites and ceramics. Finally, SERDP will act as a catalyst in fostering the development of next generation concepts and tools, such as improved computational chemistry techniques and models which will help accelarate the development of environmentally friendly DoD materials and processes.

The objective of the first SERDP SON, **Reduced Particulate Matter (PM) Emissions For Military Gas Turbine Engine Applications**, is to develop and evaluate fuel formulations and additives and/or hardware solutions that will mitigate the formation of particulate matter (PM) in jet fuels and/or reduce particulate matter mass concentrations in the exhaust of gas turbine engines burning JP-8, JP-5, and diesel fuel. Military gas turbine engines are a significant source of particulate matter less than 2.5 microns in diameter ($PM_{2.5}$). The cost-effectiveness of the approach, impact on the environment, and the ability to meet DoD mission requirements will be considered critical factors. The proposed solutions shall be applicable to military engines which:

- Require wider fuel tolerance with the minimum of Diesel #1 (DF1), Diesel #2 (DF2), DFA, JetA and JP-8, including fuels of uncertain composition in overseas and emergency operations;
- Have a duty cycle including operation at light load for significant time periods;
- Operate in more harsh environments including water fording, heavy dust, and mud, and;
- Have space and performance constraints, which may impact the unit's ability to meet mission requirements.

The second SERDP SON, **Gaseous Emissions and Particle Formation in the Combustion Zone for DoD Gas Turbine And Diesel Engines**, intends to develop a better understanding of the combustion process in gas turbine and diesel engines in order to improve the predictability of polycyclic aromatic hydrocarbon (PAH) formation and better understand the role of PAHs in soot formation. This knowledge will permit the prediction of the formation of all particulate matter below 10 micrometers. Any computer models developed to support this effort must be compatible with existing computational fluid dynamic models of engines and be applicable to military engines.

The third SERDP SON, **Environmentally Acceptable Pyrotechnic Formulations**, intends to develop environmentally friendly pyrotechnics for DoD applications. Pyrotechnics can be grouped into six families: 1) decoy flares, 2) illuminating flares, 3) colored flares, 4) smokes (both colored and white), 5) igniters/starters, and 6) miscellaneous pyrotechnic items. The focus of this SON is to reduce the environmental effects of these devices through: 1) reformulation of the materials in the device to reduce or eliminate toxic or carcinogenic constituents or reaction products; or 2) changes to manufacturing/fabrication process which reduce or eliminate the use of hazardous solvents.

The fourth SON, **Environmentally Innovative Technologies for Low Observable Coatings Applications - Removal and Repair**, will develop environmentally benign applications, and removal and repair processes for electro-radiation effects coatings that meet Low Observable (LO) requirements of DoD weapon systems. These specialty coatings contribute greatly to the military mission and often are enabling technologies. Proposed work can focus on any of the following special use coatings: conductives, MagRAM, carbon filled, or other LO coatings. Radar absorbing materials for all applicable weapon systems are within the scope of this effort, however, Chemical Agent Resistant Coatings (CARC) will not be considered.

In addition to these core SONs, SERDP is also soliciting SEED proposals in the following four topic areas to develop high risk/high payoff research and development efforts to address the DoD pollution prevention needs.

The first SEED SON, **Environmentally Benign Ceramic Materials for DoD Systems**, will develop innovative approaches to eliminate or reduce the use of toxic materials in the production, maintenance and repair of ceramic materials in DoD applications. The development of environmentally benign, alternative chemistries and production and repair processes for DoD ceramic materials will result in a reduction in the use of toxic ingredients, reagents and solvents associated with the manufacture and maintenance of ceramic armor and sensors.

The second SEED SON, **Environmentally Benign Production, Maintenance and Repair of Military Composite Structures**, will develop innovative approaches to eliminate or reduce the use of toxic materials in the production, maintenance and repair of DoD composite structures and minimize the generation of hazardous and toxic waste resulting from these processes.

The third SEED SON, **Computational Chemistry Methods for Development of Environmentally Benign Materials and Processes**, will seek to develop improved computational chemistry techniques to accelerate the development of environmentally benign chemicals and processes to reduce DoD use of hazardous and toxic materials in its weapons systems and munitions. These techniques will reduce the cyclic process of synthesis and test and re-synthesis and expand the potential for the development and use of new approaches to address DoD materials requirements.

The fourth and final SEED SON, **Environmentally Benign Primer/ Igniter Systems**, will develop systems to eliminate and reduce the use of toxic materials in the manufacture and maintenance of igniter or primer materials and systems in DoD applications. The focus of this program is to evaluate innovative approaches to reduce the environmental effects of these materials through reformulation or changes to manufacturing and fabrication processes. Alternative, non-chemical approaches to perform the function of igniters and primers will also be considered.

Detailed descriptions of the FY 2001 Pollution Prevention Statements of Need may be found in Appendix E.

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# APPENDIX A
## Cleanup Project Summaries


| ID# | Project Title | Page |
|---|---|---|
| CU-368 | Aquifer Restoration by Enhanced Source Removal | A-3 |
| CU-720 | Federal Integrated Biotreatment Research Consortium (FIBRC): Flask to Field Initiative | A-5 |
| CU-861 | National Environmental Technology Test Sites (NETTS) Program–McClellan AFB, CA | A-7 |
| CU-863 | National Environmental Technology Test Sites (NETTS) Program–Naval Construction Battalion Center (CBC), Port Hueneme, CA | A-8 |
| CU-864 | National Environmental Technology Test Sites (NETTS) Program–former Wurtsmith AFB, MI | A-9 |
| CU-866 | National Environmental Technology Test Sites (NETTS) Program–Dover AFB, DE | A-11 |
| CU-1062 | Development of Simulators for In-Situ Remediation Evaluation, Design, and Operation | A-13 |
| CU-1064 | Bioenhanced In-Well Vapor Stripping to Treat Trichloroethylene | A-15 |
| CU-1070 | Low-Frequency Ultra-Wideband Boom Synthetic Aperture Radar (Boom-SAR) for Remote Detection of Unexploded Ordnance (UXO) | A-17 |
| CU-1071 | Unexploded Ordnance (UXO) Detection by Enhanced Harmonic Radar | A-18 |
| CU-1073 | Using Mode of Action to Assess Health Risks from Mixtures of Chemical/ Physical Agents | A-19 |
| CU-1080 | Value-Added Site Monitoring & Infrastructure Maintenance for In-Situ Bioremediation | A-21 |
| CU-1081 | Genosensor-Based Ecotoxicity Response Assessment | A-22 |
| CU-1089 | Negative Ion Sensors for Real-Time Downhole DNAPLs Detection | A-24 |
| CU-1090 | Integrated Geophysical Detection of DNAPL Source Zones | A-26 |
| CU-1091 | Innovative Seismic System for Buried Unexploded Ordnance Detection and Classification | A-27 |
| CU-1092 | Model-Based Data Fusion and Discrimination of UXO in Magnetometry and EM Surveys | A-28 |
| CU-1093 | In-Situ Clay Formation: A New Technology for Stable Containment Barriers | A-29 |
| CU-1094 | Environmental Impacts to the Chemical Signature Emanating from Buried UXO | A-31 |
| CU-1095 | Assessment and Prediction of Biostabilization of Polycyclic Aromatic Hydrocarbons (PAH) in Sediments | A-33 |
| CU-1121 | Processing Techniques for Discrimination between Buried Unexploded Ordnance and Clutter Using Multisensor Array Data | A-34 |
| CU-1122 | UXO Discrimination by Mid-Frequency Electromagnetic Induction | A-36 |
| CU-1123 | Statistical Signal Processing with Physics-Based Models: Multi-Sensor UXO Detection and Identification | A-38 |
| CU-1124 | An Innovative Passive Barrier System Using Membrane-Delivered Hydrogen Gas for the Bioremediation of Chlorinated Aliphatic Compounds | A-40 |
| CU-1125 | Influence of Groundwater Constituents on Longevity of Iron-Based Permeable Barriers | A-42 |
| CU-1127 | Development of Effective Aerobic Cometabolic Systems for the In-Situ Transformation of Problematic Chlorinated Solvent Mixtures | A-44 |
| CU-1128 | Nonintrusive Characterization of Dense Nonaqueous Phase Liquids Using Short-Lived Radiotracers in Partioning Interwell Tracer Tests | A-46 |

| ID# | Project Title | Page |
|---|---|---|
| CU-1129 | Biological Assessment for Characterizing Contaminant Risk at the Genetic-, Individual-, and Population-Level | A-47 |
| CU-1140 | Evaluation of Performance and Longevity at DoD Permeable Reactive Barrier Sites | A-49 |
| CU-1141 | Environmental Toxicology Earmark | A-50 |
| CU-1162 | In-Situ Bioreduction and Removal of Ammonium Perchlorate | A-52 |
| CU-1163 | In Situ Bioremediation of Perchlorate | A-54 |
| CU-1164 | In Situ Bioremediation of Perchlorate-Impacted Groundwater | A-56 |
| CU-1165 | Proposal to Develop Extraction Tests for Determining the Bioavailability of Metals in Soil | A-57 |
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| CU-1170 | Assessment of the Potential for Microgravimetry in Remote Discrimination and Identification of Buried UXO (*SEED project*) | A-66 |
| CU-1171 | Multiple Frequency Induction Measurements for Enhanced Buried UXO Discrimination (*SEED project*) | A-68 |
| CU-1172 | Novel Acoustic Technique for UXO Discrimination (*SEED project*) | A-70 |
| CU-1173 | SAR/GPR Matched Filter Processing for UXO Discrimination (*SEED project*) | A-72 |
| CU-1174 | Detection and Classification of Buried Metallic Objects (*SEED project*) | A-73 |
| CU-1175 | Fe(O)-Based-Bioremediation of RDX-Contaminated Aquifers (*SEED project*) | A-75 |
| CU-1176 | In-Situ Remediation of Explosives Contaminated Groundwater with Sequential Reactive Treatment Zones (*SEED project*) | A-77 |
| CU-1177 | Novel Approach for Stimulating Reductive Dechlorination | A-78 |

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Aquifer Restoration by Enhanced Source Removal; CU-368

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Carl Enfield; National Risk Management Research Lab – Ada, OK

**FY 2000 FUNDS:** $200K

**DESCRIPTION:** Low-solubility organics such as chlorinated solvents were used and released to the environment in large quantities during the 1950s, '60s, and '70s. These contaminants have migrated through the subsurface and entered groundwater at more than 1,000 Department of Defense (DoD) sites. At these sites, the organic contaminants are found in one of four phases: (1) volatilized within the soil's vadose zone (vapor phase), (2) dissolved in the groundwater (dissolved phase), (3) sorbed to the aquifer solids (sorbed phase), or (4) as a separate non-aqueous phase liquid (NAPL) phase. All of these phases contribute to groundwater contamination.

The limiting factor to satisfactory remediation at over 75 percent of the hazardous waste sites in the United States is the restoration of groundwater quality. The major limitations of the successful use of pump-and-treat technology are related to difficulties in extracting contaminants from source areas where NAPLs exist. The objective of this research is to evaluate extraction processes (solubilization and mobilization), which have been developed at the bench scale, for their potential to enhance extraction in the source area. The technologies will be evaluated using field pilot-scale cells for side-by-side comparison of technologies.

The proposed work will be a series of field demonstrations of enhanced extraction technologies supported by site characterization and laboratory research required to produce credible field demonstrations and evaluations. The work will focus on remediation of source areas of sites believed to be contaminated by NAPLs at residual concentration (no longer mobile and, therefore, not readily available for extraction by pumping).

The processes will be demonstrated at two sites with varying hydrogeologic characteristics and chemical mixtures (both NAPLs and sorbed contaminants will be considered) to determine their performance under a variety of conditions. The tests will be conducted as controlled, small-scale field projects. Each technology will be compared to one or more alternative remediation technologies including conventional pump-and-treat as a reference treatment system. The results of these comparisons will show the differential improvement achieved by one process relative to another. Success of the project will be dependent on the ability to obtain access to actual sites; and to obtain regulatory permission to perform non-standard, pilot-scale evaluations without significant delay.

**BENEFIT:** It is estimated that over 90 percent of the contaminants in the subsurface environment are contained in the source area. Until the source area is remediated or contained, it will not be possible to obtain permanent closure for any of the sites. Pump-and-treat systems are the primary technology in use at sites with contaminated groundwater. Because of their inability to effectively clean contaminant sources, many of them will be operated "in perpetuity." The cost of operating and maintaining these systems is enormous, and the institutional arrangements to keep them operating for tens to hundreds of years do not exist. Bench-scale studies suggest that it will be possible to remove the majority of the NAPL where the source can be identified. The time required for this removal is small compared to the time required if pump-and-treat technologies are used. Estimated costs for groundwater remediation by DoD and other Federal agencies range into the hundreds of billions of dollars, and even incremental improvements in efficiency will justify the cost of the proposed research.

**ACCOMPLISHMENTS:** The first technology demonstration at the Dover AFB National Test Site used ethanol as a flushing agent to accelerate dissolution of the Dense Non-Aqueous Phase Liquids (DNAPL).

The field test was completed in June, 1999. Results suggest that approximately 70 percent of the DNAPL was removed during this test. A second demonstration which combines air sparging below the water table with soil vapor extraction in the vadose zone is currently nearing completion. Preliminary results suggest that a large fraction of the DNAPL mass was removed with this approach. System modeling and additional field hydraulic characterization has been initiated in order to improve the sweep efficiency of remedial fluids used during the demonstrations.

**TRANSITION:** The results of these comparisons between alternative remediation technologies will be compiled into a manual. This manual will be prepared for the user community to facilitate design of these systems. The design manual will contain anticipated system performance and will be made widely available to facilitate transition of the technology developed.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Federal Integrated Biotreatment Research Consortium (FIBRC): Flask to Field Initiative; CU-720

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Jeffrey W. Talley; U.S. Army Corps of Engineers Engineer Research and Development Center, Environmental Laboratory – Vicksburg, MS

**FY 2000 FUNDS:** $2,300K

**DESCRIPTION:** The objective of this project is to develop a set of "realistic" biotreatment processes for the cleanup of several classes of contaminants at Department of Defense (DoD) sites. A single, panacea technology for each contaminant group that can be used at all DoD sites will not be obtained. All treatment processes have technical and economic limitations, and part of the experimental process of this program will be to define these limitations.

The technical approach of this project is to investigate a variety of promising biotreatment processes at the bench and intermediate scale. The experiments in this program will be directed toward four major contaminant areas: (1) explosives, (2) chlorinated solvents, (3) polychlorinated biphenyls (PCB), and (4) polycyclic aromatic hydrocarbons (PAH). In some cases, the concepts under investigation have been developed by members of this consortium. In other cases, other concepts that indicate promise were taken from current literature and professional affiliation. The technical approach and processes under development have the potential to be fielded within a reasonable amount of time. This approach will ensure that the DoD will have more cost-effective remediation technology within a time frame required for DoD site remediation activities. Biotreatment processes will be evaluated for the following four major contaminant groups:

- ***Explosives Contaminated Soils And Groundwaters.*** A variety of promising biotreatment techniques will be investigated for remediation of soil and groundwater contaminated with explosives compounds. Explosives contamination represents one of the most prevalent types of organic contamination within the DoD. The research projects in this thrust area are: (a) Discovery of Novel Enzymatic Reactions and Determination of Biodegradation Mechanisms and Pathways and (b) Chemical Transformation followed by Biotreatment for Treatment of TNT Contaminated Groundwater.

- ***PAH Contaminated Soils.*** This group of contaminants represents the most regulated of PAH compounds due to their carcinogenic properties. Also, because of their large and complex molecular structure, they also represent the most difficult of all the PAHs to biologically degrade. The research projects in this thrust area are: (a) Management of Bioremediation of Soils Contaminated with Heavy Molecular Weight PAHs through Bioaugmentation and Bioavailability Enhancement and (b) Intermittently Mixed Reactor System for Enhancement of Mass Transfer and Bioavailability in the In-Situ Treatment of hPAH-Contaminated Soils.

- ***Chlorinated Solvent Contaminated Soils and Groundwaters.*** Chlorinated solvents represent a class of contaminants that is detected at more DoD sites than any other contaminant group. The research projects in this thrust area are: (a) Electrically-induced In-Situ Reductive Dechlorination of Chlorinated Solvents and (b) In-Situ Solvent-Extraction-Residual-Biotreatment of Chlorinated Solvents.

- ***PCB Contaminated Soils.*** Soils contaminated with PCBs represent one of the most challenging compound groups under investigation in this project. PCBs are found at many DoD installations due to improper disposal of hydraulic fluids and waste lubricating oils. The research project in this thrust area is: Enhancing PCB Biodegradation.

**BENEFIT:** The primary benefit of this study is reduced remediation costs associated with development of "realistic" biotreatment processes for the cleanup of contaminated DoD sites. Secondary benefits include: expanded implementation potential of existing and developing biotreatment processes, biotreatment technologies that result in the on-site destruction of contaminants, and increased regulatory and user acceptance.

**ACCOMPLISHMENTS:** The horse-race concept of process development, adopted at the earlier stages of the Consortium, was transitioned into a project mode of process development during FY98, in keeping with the recommendations of the SERDP Scientific Advisory Board (SAB) and the FIBRC Technical Advisory Committee (TAC). As a result, five projects were funded in FY99 (1 in the Explosives thrust area, 1 in the hPAH thrust area, 2 in the Chlorinated Solvents thrust area, and 1 in the PCB thrust area). These projects emphasized field demonstration within two years as their goal. Design and costing activities were made part of each project. These projects included continued field testing of biotreatment of solvent-extraction residual DNAPL, intermediate scale testing of biotreatment of soil contaminated with mixtures of dinitrotoluene (DNT). Research teams for field/pilot testing of technologies were established and coordinated. Pilot demonstration of biological treatment of groundwater contaminated with mixtures of 2,4-DNT and 2,6-DNT in a continuous fluidized bed reactor, using microbial strains and technology developed by Dr. Jim Spain (Air Force Research Laboratory) under the auspices of FIBRC, was completed at Volunteer AAP in FY98. A report for this activity, including a cost analysis of this technology, was submitted to SERDP office in March 1999.

**TRANSITION:** This project will develop for the DoD community a biotreatment "toolbox" that can be drawn upon to offer the right process for each site. The technologies produced by this project are intended to serve remediation project managers who want options and well defined limitations of each option made available to them during their remediation efforts. Each process, whether it is traditional or innovative, has technical limitations and risks associated with its fielding. The knowledge of these process limitations will be required to reduce the risks accepted by the installation and regulatory agencies to an acceptable level.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** National Environmental Technology Test Sites (NETTS) Program – McClellan AFB, CA; CU-861

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Jim Lu; McClellan Air Force Base – Sacramento, CA

**FY 2000 FUNDS:** $290K

**DESCRIPTION:** The National Environmental Technology Test Site (NETTS) program goal is to enable efficient demonstration of innovative detection, monitoring or cleanup technologies, either on an individual basis or in parallel with similar projects, under representative hydrological and climate regimes as found at many contaminated sites in the Department of Defense (DoD). Current environmental cleanup technologies are costly, slow, and largely ineffective. The NETTS program provides test beds for research to fully understand the mechanisms in proposed treatment processes. The NETTS National Test Location at McClellan Air Force Base (AFB) provides test sites to investigate technologies for treatment of unsaturated soils and extracted soil-gas contaminated with chlorinated solvents, as well as ex-situ treatment of contaminated groundwater.

As a NETTS test location, McClellan AFB provides a well-characterized demonstration site for applied research, demonstration, and evaluation of promising cleanup and monitoring technologies. McClellan AFB currently has four operational and two planned soil vapor extraction (SVE) systems. All systems have dedicated utilities adjacent to them allowing for convenient slip-stream demonstrations. McClellan AFB's groundwater treatment plant currently services 23 extraction wells. The SVE systems and groundwater treatment facility provide opportunities for demonstrating in-situ and ex-situ techniques for remediating soils and groundwater contaminated with solvents. There are more than 375 groundwater monitoring wells located on and around McClellan AFB.

**BENEFIT:** Test locations are fully characterized. The NETTS test locations help save time and money for technology demonstrations by providing on-site management, pre-characterization, and timely permitting. An established, dedicated test site will enable technology demonstrations to be performed at a cost lower than that of a one-time demonstration elsewhere.

**ACCOMPLISHMENTS:** In FY99, the McClellan AFB NETTS location accomplished the following: published 2 papers, issued 6 final work plans for FY 99 new start projects, issued Technology Application Analysis Reports for 3 FY99 project completions, provided support to Principle Investigators (PI) for Work Plan development for 10 FY99 new start projects, provided support to PIs for Technology Application Analysis Report, preparations for 10 FY99 field completions, and provided infrastructure and Regulatory Compliance support to 29 ongoing and new start projects

**TRANSITION:** This project will continue to support the transition of technology as defined by the NETTS Mission Statement that reads: Provide accessible, well-supported field locations for proof-of-principle, applied research, and comparative demonstrations and to facilitate transfer of innovative environmental technologies from research to full scale use.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** National Environmental Technology Test Sites (NETTS) Program – Naval Construction Battalion Center, Port Hueneme, CA; CU-863

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Ernest Lory; Naval Facilities Engineering Service Center – Port Hueneme, CA

**FY 2000 FUNDS:** $670K

**DESCRIPTION:** The objective of the Navy Construction Battalion Center (CBC) National Environmental Technology Test Sites (NETTS) National Test Location (NTL) at Port Hueneme, CA, is to support demonstration of technologies for characterizing and remediating soil, sediments, and groundwater contaminated with fuel hydrocarbons and/or waste oil. It provides test sites to investigate both ex-situ technologies for treatment of soils and in-situ technologies for groundwater contaminated with fuel hydrocarbons. The Test Location Manager (TLM) at CBC, Port Hueneme provides programmatic, infrastructure and technical support to researchers for fuel hydrocarbon and waste oil characterization and remediation demonstrations. Programmatic support will include integration of the following: (1) Quality Assurance/Quality Control (QA/QC) procedures, (2) test protocol guidance, (3) demonstration reporting format, and (4) environmental setting, cost-and-performance data retrieval guidance. Infrastructure and its management (operation and maintenance) will include: (1) monitoring wells, (2) in-line sensor network, (3) ex-situ treatment facility with hazardous material handling capability, (4) utilities, and (5) contaminated soil, sediments and groundwater resources. Technical support will include: (1) characterizing and monitoring contaminants, (2) processing permits, (3) supporting stakeholder involvement, and (4) transferring technologies.

**BENEFIT:** The NTL for fuel hydrocarbon and waste oil provides well characterized test locations, controlled field conditions for comparative evaluations of technologies, uniform evaluation criteria for demonstrations, reporting of results and technology transfer, and cost savings through amortization of infrastructure and management.

**ACCOMPLISHMENTS:** In FY99, the Port Hueneme NETTS test location provided support to the University of California (UC) Santa Barbara Hollow Fiber Membrane demonstration from June 14-25. All field operations were in permit compliance.

The Port Hueneme NETTS test location hosted an UC Santa Barbara Methyl Tertiary Butyl Ether (MTBE) 2000 Project Advisory Committee meeting which kicked off the MTBE eco-risk evaluation of the NEX plume. The Advanced Fuel Hydrocarbon Remediation Department of the CBC at Port Hueneme, CA, emphasizes fuel hydrocarbon remediation in soil and groundwater. Its mission is to develop and maintain research and development platforms for testing, evaluation, and validation of promising environmental cleanup and monitoring technologies. This NETTS location has established a network of environmental engineers, regulators, and experts from industry and academia to address MTBE remediation in soil and aquifers. It also manages a test platform at the Port Hueneme Navy Exchange for evaluating ex-situ and in-situ characterization, monitoring and remediation technologies. This test platform is a well-characterized site where technologies can be field-tested under known conditions against established standards. To address the DoD and national concern about remediating MTBE contaminated sites, a number of remediation technologies, fate and transport model enhancements, and risk analyses are being evaluated at the SERDP-funded Port Hueneme NETTS location.

**TRANSITION:** This project will continue to support the transition of technology as defined by the NETTS Mission Statement that reads: Provide accessible, well-supported field locations for proof-of-principle, applied research, and comparative demonstrations and to facilitate transfer of innovative environmental technologies from research to full scale use.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** National Environmental Technology Test Sites (NETTS) Program – former Wurtsmith AFB, MI; CU-864

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Michael Barcelona; University of Michigan, National Center for Integrated Bioremediation Research & Development – Oscoda, MI

**FY 2000 FUNDS:** $462K

**DESCRIPTION:** The objective is to operate and maintain a National Environmental Technology Test Sites (NETTS) National Test Location at the National Center for Integrated Bioremediation Research and Development (NCIBRD) which investigates advanced technologies in site characterization, decontamination of hazardous wastes, and remediation of spill and disposal sites. Under NETTS, well-characterized test sites are provided for technologies with evident promise for complete and cost-effective remediation with minimal environmental disruption, which are favored for facility usage. These technologies involve on-site and in-situ processes which integrate biological and physicochemical methods for treatment of soils and groundwater contaminated with fuels, chlorinated solvents, and organic mixtures. NCIBRD is located at the recently decommissioned Wurtsmith Air Force Base (AFB) in Oscoda, Michigan, which has numerous fuel and chlorinated solvent contamination sites resulting from former Air Force activities.

Activities at NCIBRD include an array of research, development, demonstration, testing and evaluation efforts toward the transfer of field and laboratory findings into successful remediation practice. The program focuses on several specific problems relating to the development of core biotechnologies such as the enhanced understanding of microbiology and microbial geochemistry, improved means for implementing biotechnology in engineering applications, and accelerated bioremediation of contaminated soils and groundwater. Controlled programs on site characterization and in-situ integrated remediation technologies for decontamination of hazardous substances in wastes, soils, and groundwater are conducted at the facility. The majority of the sites at the base have been characterized to some extent. Several of the larger sites are under hydraulic control by way of pump-and-treat systems. A subset of three fuel and chlorinated solvent sites have been characterized geochemically and microbially in support of in-situ bioremediation. The facilities provide a focal point for coordination and cooperation within the broad community of institutions, agencies, and corporations currently attempting to develop these technologies.

**BENEFIT:** This test location provides significant direct and indirect benefit to the Department of Defense (DoD), Department of Energy (DOE), and Environmental Protection Agency (EPA) Environmental Research and Development (R&D) programs by enabling advanced site characterization and remediation technologies to be evaluated on a common baseline. It also provides standardized testing procedures and cost-and-performance evaluation guidelines which should expedite the approval process for new technologies and in turn facilitate the transfer of those technologies from the development stage to operational use. Field-scale testing at sites which are well characterized and monitored on a continuing basis will save considerable amounts of money in evaluating individual technologies for DoD use.

**ACCOMPLISHMENTS:** In the past five years, the effort has successfully supported the field activities of eighteen site characterization and cleanup technologies. At least four sites of major activity have been well instrumented and a database has been established to attract future projects. A long list of related collaborative publications has been distributed to interested parties. Also a periodic newsletter has been published for the last three years and distributed to more than 2,000 practitioners in the field. The newsletter chronicles NCIBRD progress and provides news notes on remediation. Currently, the effort supports ten ongoing demonstrations and expects an additional four sites within the next few months. Cost-recovery from demonstrations has been useful towards meeting base budget needs. The current level of activity is the highest since 1995.

**TRANSITION:** This project will continue to support the transition of technology as defined by the NETTS Mission Statement that reads: Provide accessible, well-supported field locations for proof-of-principle, applied research, and comparative demonstrations and to facilitate transfer of innovative environmental technologies from research to full scale use.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** National Environmental Technology Test Sites (NETTS) Program – Dover AFB, DE; CU-866

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Tim McHale; Air Force Research Laboratory – Tyndall Air Force Base, FL

**FY 2000 FUNDS:** $507K

**DESCRIPTION:** This National Environmental Technology Test Sites (NETTS) National Test Location, which is managed by the Air Force Research Laboratory, provides test sites for the application of characterization and remediation technologies to soil and water contaminated by chlorinated solvents. Its centerpiece is the Groundwater Remediation Field Laboratory (GRFL). The GRFL consists of isolated, well-monitored, in-situ controlled release test cells, in which mass-balance studies of the fate, transport and remediation of Dense Non-Aqueous Phase Liquids (DNAPL) may be performed.

Operations consist of long-term monitoring of the site, as well as project support to include injection of the constituent (Trichloroethylene primarily), demonstration of innovative technologies, and disposal of a minimal amount of waste from the tests. The GRFL program consists of construction of a maximum of five test cells spaced approximately 50 feet apart and constructed and operated in a way to minimize the potential for environmental contamination. Basic design consists of interconnected, steel barrier piling sections (2 feet wide) forming a rectangular pattern (test cells range in aereal size up to 600 square feet). By driving the sheet piling 3-5 feet into the clay aquitard (approximately 30 - 40 feet from the surface), a coffer is formed which prevents vertical and lateral migration outside the confines of the box. There is an additional secondary containment coffer surrounding the primary coffer, which is similarly sealed at the bottom and at each joint. The annulus between the cells is filled with water to produce an inward hydraulic gradient. The annulus and inner cell are continuously monitored for leakage. There are both upgradient and downgradient monitoring wells outside the secondary coffer. Other sheet pile designs to be considered include geomembrane and grout type barriers. Risks are minimal for the program as designed and can be controlled. Primary risk is that introduced material will escape and contaminate an aquifer. Vertical migration is retarded very well by a twenty foot thick underlying clay layer with a hydraulic conductivity four orders of magnitude less than the overlying strata. Double sheet piling, grouting, monitoring, developing emergency pump-and-treat system, and distance to the nearest potential users of the aquifer virtually eliminate the risk from lateral migration. The process for obtaining permits for contained releases is established and it is expected to take less than 90 days per permit application.

**BENEFIT:** The GRFL is a unique resource, the primary purpose of which is to provide contained release cells for DNAPL research and development that avoid making the gross assumptions that would be necessary if experiments were conducted in previously contaminated aquifers. DNAPLs are immiscible with and denser than water, and when spilled on the ground, migrate below the water table. Once below the water table, they are difficult to locate and remove. Currently there are no acceptable methods for removing or treating DNAPLs. Technologies must be developed to protect the public from the potential health risks associated with DNAPLs in drinking water.

**ACCOMPLISHMENTS:** Dover National Test Site (DNTS) supported the following projects during FY99 by providing: (1) support to the EPA/SERDP Enhanced Source Removal Demonstrations, (2) completion of the University of Florida cosolvent solubilization test and start-up of the air sparging/soil vapor extraction test (included another Perchloroethylene (PCE) release), (3) analytical support (twice monthly) to the Principal Investigator for the Remediation Technologies Development Forum (RTDF)/EPA Cometabolic Bioventing, (4) characterization via cone penetrometry for evaluation phase for the RTDF Intrinsic Bioremediation, (5) support to the Permeable Reactive Barriers in the final sampling round, work planning, plume location, and construction oversight phases and support of the overall project via contracting support

to set up labor and services for spin off projects, and (6) assistance in the characterization of the plume for the Bioaugmentation for Anaerobic Dechlorination Phase II.

**TRANSITION:** This project will continue to support the transition of technology as defined by the NETTS Mission Statement that reads: Provide accessible, well-supported field locations for proof-of-principle, applied research, and comparative demonstrations and to facilitate transfer of innovative environmental technologies from research to full scale use.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Development of Simulators for In-Situ Remediation Evaluation, Design, and Operation; CU-1062

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Mark Dortch; U.S. Army Corps of Engineers Engineer Research and Development Center, Environmental Laboratory – Vicksburg, MS

**FY 2000 FUNDS:** $480K

**DESCRIPTION:** The ultimate goal in remediation modeling is to minimize remediation costs and environmental and human risks while maximizing remediation effectiveness. Toward this end, the general goals of this project are: (1) to develop reliable simulators for promising technologies of interest to Department of Defense (DoD), Department of Energy (DOE), and the regulatory community, and (2) to provide efficient access to multiple remediation simulators through a common user environment amenable to multi-disciplinary cleanup teams. A common, graphical user environment has been developed for these simulators; it is the DoD Groundwater Modeling System (GMS). The GMS provides conceptualization, parameterization, visualization, and animation capabilities. Additionally, GMS extensions, either ongoing or planned, will provide capabilities for conducting remediation, uncertainty, optimization, and cost analyses. The primary technical objectives of this project are to: (1) develop/enhance state-of-the-art remediation simulators for the following technologies: in-situ bioremediation; surfactant-enhanced bioremediation; electrokinetic-enhanced bioremediation; electrokinetic-enhanced mobilization of metals; natural attenuation of explosives; in-situ chemical treatment; surfactant/cosolvent flushing; soil vapor extraction; and air sparging; (2) verify these simulators against available laboratory and field data; and (3) incorporate these simulators into the GMS to provide DoD, DOE, and other users with the computational ability to assess the tradeoff between environmental risk (cleanup level) and cost-effectiveness for a variety of cleanup technologies prior to their implementation.

Remediation simulator development will proceed along three paths, in order of priority: (1) utilize existing, proven remediation simulators where available and consistent with project goals, (2) modify promising groundwater codes to simulate additional technologies as appropriate, or (3) develop new codes as required for efficient simulation of innovative technologies. All simulators will be verified against available laboratory and field data. Results of these evaluations and the simulator codes will be documented. Each simulator will be implemented in the GMS. This project strongly leverages technical partnering and collaboration with ongoing and proposed basic and applied research in subsurface flow, contaminant fate/transport, remedial methods, remediation simulation under heterogeneous subsurface conditions, GMS-user environment development, and high performance computing in environmental quality modeling. Technical risk issues involve: (1) uncertainty regarding key processes in complex remediation technologies; (2) the scarcity of experimental or field data for innovative technologies; and (3) the general adequacy of differing computational resources on which to run complex models efficiently. Leveraging against the new Common High-Performance Scalable Software Initiative and Army High-Performance Computing efforts will address several of the high-performance computing issues associated with simulator development and execution.

**BENEFIT:** The GMS-based simulators will permit efficient evaluation of multiple remediation technologies for site-specific conditions, allowing selection of effective and cheaper cleanup actions. Such simulators are needed to support advocacy for biogeochemically complex alternatives that are faster, more effective, and/or more cost-efficient than traditional methods. Simulators will improve the remedial design by permitting cleanup specialists to consider multiple scenarios that could increase cleanup effectiveness.

**ACCOMPLISHMENTS:** During the first two years, modifications were made to the four simulators to make them more suitable to simulating their targeting remediation technologies. Validation applications and

GMS implementations were initiated during the second year of the project, FY98. Similar work was continued during FY99. Accomplishments during FY99 are summarized below.

- Training course on The University of Texas Chemical Flood Simulator (UTCHEM) was conducted.
- Cosolvent flushing simulation validation with lab column data using UTCHEM was completed.
- Natural Attenuation (NA) simulation validation for the Natural Attenuation Test Sites (NATS) site using Sequential Electron Acceptor Model (SEAM3D) was completed.
- Engineered bioremediation simulation validation at Defense Fuel Supply Point (DFSP) using SEAM3D was completed.
- GMS implementation of UTCHEM for flushing technologies was conducted, and GMS implementation of Operator Splitting in 3D (OS3D) was initiated.
- GMS interface testing for SEAM3D and Non-isothermal Unsat./Sat. F&T in 3D (NUFT3D) was conducted.
- Advanced natural attenuation of explosives (NAX) simulator code developments were completed.
- SEAM3D was modified to allow simulation of cometabolism and reductive dehalogenation.
- Final draft user's manual/documentation reports for SEAM3D (v2.0), Modular transport 3-D (MT3D) (v3.5), and UTCHEM (v8.0) were prepared.
- In-Situ Chemical Treatment (ISCT) (with reduced iron barrier) validation simulations using OS3D were completed for the Dover GRFL and were initiated for Moffett Field.

**TRANSITION:** The project will transition the GMS-based simulators directly to users that include DoD, DOE, EPA, and other groundwater and environmental professionals involved in hazardous waste site cleanup. Use of these remediation simulators will allow more reliable comparison between cleanup level (its duration, environmental risk level) and the cost of each level of cleanup.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Bioenhanced In-Well Vapor Stripping to Treat Trichloroethylene; CU-1064

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Mark N. Goltz; Air Force Institute of Technology, Wright Patterson AFB, OH.

**FY 2000 FUNDS:** $191K

**DESCRIPTION:** The objective of this project is to demonstrate the potential of combining two innovative, recently demonstrated, remediation technologies, in-well vapor stripping and in-situ aerobic cometabolic bioremediation, to remediate an area contaminated with separate phase Dense Non-Aqueous Phase Liquid (DNAPL). This hybrid treatment system will be installed and tested at a chlorinated solvent contamination site at Edwards AFB, CA.

After installation, the system will be turned on for initial operation and tracer testing. Initial operation and testing will consist of turning on the biotreatment well pump and the in-well vapor stripper blower to effect water flow through the system. Flow through the in-well vapor stripper will be determined using a tracer. It is anticipated (based upon preliminary modeling results) that water flows through the biotreatment wells and the in-well vapor stripping well will be set to approximately 8 gallons per minute. Groundwater levels will be monitored using the monitoring wells and the pressure transducers located at the bottom and top of the treatment wells. A bromide tracer (50 mg/L) will be added at the chemical addition port of the biotreatment wells. Use of a tracer will provide an understanding of the system's hydraulics and allow verification of the modeling results. By comparing bromide concentrations at the vapor stripping well outlet and the surrounding monitoring wells, the non-volatile bromide tracer will provide a baseline, against which Trichloroethylene (TCE) measurements can be compared, specifically to quantify TCE volatilization in the vadose zone. The initial operational testing will also measure pH, dissolved oxygen and TCE levels in the system. Based on dissolved oxygen levels at the inlet to the biotreatment well, the amount of oxygen to be added in the well to support the aerobic cometabolism can be calculated. Continuous, on-line pH measurements of the vapor stripping well effluent will be used to control a chemical feed pump supplying dilute hydrochloric acid to the influent of the vapor stripping well, in order to minimize chemical precipitation. Finally, as part of the initial operation phase, toluene will be introduced in a single pulse in the biotreatment wells and then the system will be shut off. This step will be used to allow a toluene degrading consortium of bacteria to grow in the bioactive zones, as well as to demonstrate that toluene will be degraded.

During full-scale system operation, toluene will be pulsed into the system to provide the time-averaged concentration determined to be necessary based on the preliminary studies. This pulsing schedule will be adjusted as necessary to optimize system performance over the six-month course of the demonstration. Oxygen gas will continuously be added at the biotreatment well. Hydrogen peroxide will also continuously be added as an oxygen source and bactericide to control microbial clogging at the biotreatment well. The extent of clogging will be monitored by measuring pressures at the injection screens of the biotreatment wells.

**BENEFIT:** The most obvious benefit is that this combination of technologies offers the potential of reducing, in-situ contaminant concentrations at a DNAPL contaminated site over three orders of magnitude, something which has never been demonstrated. The fact that the technologies are applied in-situ minimizes risk to human and environmental receptors, as well as reduces the costs of pumping water to the surface, treating it, and disposing of it. The technologies can be used at sites with any volatile, separate-phase contaminant that is susceptible to bioremediation by aerobic cometabolism [trichloroethylene (TCE), dichloroethylene (DCE), vinyl chloride (VC), dichloromethane, etc.].

**ACCOMPLISHMENTS:** Originally, this technology evaluation was to be conducted in a test cell at the Dover AFB GRFL. However, due to both technical and logistical problems at the GRFL, plus the advantages of implementing the project at an actual contamination site, approval was received to relocate the project to Edwards AFB. During FY99 the project has been conducting site characterization studies to define geophysical parameters of the site. Site construction commenced with the installation of treatment and monitoring wells.

**TRANSITION:** If successful at Edwards AFB, this project will transition to a full scale demonstration that combines the two remediation technologies, in-well vapor stripping and in-situ aerobic cometabolic bioremediation, to cleanup an area contaminated with separate phase (DNAPL) and dissolved phase TCE.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Low-Frequency Ultra-Wideband Boom Synthetic Aperture Radar (Boom-SAR) for Remote Detection of Unexploded Ordnance (UXO); CU-1070

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Marc Ressler; Army Research Laboratory – Adelphi, MD

**FY 2000 FUNDS:** $500K

**DESCRIPTION:** Currently, methods for detecting unexploded ordnance (UXO) involve laborious ground surveys that are slow, dangerous, and impractical for dealing with vast UXO-contaminated lands. Advanced technologies are required which are quicker, safer, and more cost-effective than current approaches. Synthetic Aperture Radar (SAR) is an advanced technology that offers significant potential for quickly and safely detecting UXO. The Army Research Laboratory (ARL) will use their precision measurement asset, called the BoomSAR, in the execution of this project. The BoomSAR is a fully polarimetric radar that operates across a 1-GHz-wide band, from 25 MHZ to 1 GHz. This bandwidth contains low frequencies needed for ground penetration, while maintaining higher-frequency coverage for high-resolution imagery. The ultra-wide bandwidth provides measured range resolution of 0.15 m; the aperture length provides cross-range resolution of 0.15 m. The radar is mounted on a boom-lift that can operate at heights of 5 to 45 m while moving at 1 km per hour, allowing the radar to operate in a strip-map SAR mode.

The goals of this project are: (1) to determine the applicability of low-frequency ultra-wideband (UWB) SAR for detecting and discriminating surface and subsurface UXO; (2) to refine and validate electromagnetic models that can be used to extrapolate UWB SAR performance to other environmental conditions (soils); and (3) to develop detection algorithms for separating UXO from clutter.

**BENEFIT:** The knowledge gained by this effort will significantly enhance the understanding of the phenomenology of UXO characterization using low-frequency UWB SAR. This effort will also help to determine the utility of the ARL BoomSAR for surveying large regions and detecting and discriminating various surface and subsurface UXO. It is expected that this technology will achieve rapid survey speeds/coverage rates while allowing safe standoff distances during operation; it will also significantly improve the detection, monitoring, and risk management activities at cleanup sites.

ARL's BoomSAR will be used to collect high-quality precision data to support phenomenological investigations of electromagnetic wave propagation through dielectric media. These investigations, in turn, will support the development of algorithms for target detection. Data will be collected at two UXO test sites that have been seeded with a comprehensive variety of inert UXO.

**ACCOMPLISHMENTS:** Extensive test sites containing a wide variety of UXO targets buried at various depths were installed at Yuma Proving Ground and Eglin AFB, and the ground truth for both sites has been thoroughly documented. A large amount of UWB radar data has been collected at both sites, and some of these data are still being processed. A CD containing radar imagery, target chips, modeling data, and test site information was finalized and delivered to SERDP in September 1999.

**TRANSITION:** The technology developed under this project will transition to users at active test and training ranges, Base Realignment and Closure (BRAC) and formerly used defense (FUD) sites, and numerous foreign countries requiring advanced technologies for locating UXO.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Unexploded Ordnance (UXO) Detection by Enhanced Harmonic Radar; CU-1071

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Ronald Stocks; National Reconnaissance Office – Chantilly, VA

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** The problem of unexploded ordnance (UXO) detection has become both acute domestically and worldwide. In the U.S. specifically, there are over 900 sites (11 million acres) of potentially UXO contaminated land of varying terrain, foliation, and topography (including 50 underwater sites). UXO cleanup represents a huge and costly problem. To date, methods of detection and remediation are at best slow and expensive and at worst crude and highly dangerous. The advantage of improved target detection techniques (especially airborne) that can aid in rapid, cost efficient and safe detection are obvious. The objective of this effort is to design, fabricate, and test a third harmonic radar to determine its efficiency in detecting surface and buried UXO of all sizes and types. In addition, the radar also will produce a capability to produce high resolution images showing their locations. This project builds on earlier work on harmonic radar and outlines the development and demonstration of a high resolution, medium range (3-4 km standoff distance) impulse driven synthetic aperture radar.

**BENEFIT:** The immediate benefit to be realized from this effort is a prototype system with a demonstrated capability to remotely detect and locate surface and shallow-buried UXO. If successful, this effort will provide the UXO remediation community with a capacity not now available. The radar system will be capable of standoff "broad area" search at relatively low cost and provide greater efficiency in removal and/or cleanup. The radar system will be an operational prototype that could be used for subsequent contractor-supported operations. The radar could also be modified to fit on a variety of aircraft of helicopter platforms. In addition, this technology should be of interest to a variety of other Department of Defense (DoD)/Department of Energy (DOE) environmental, military, and law enforcement objectives.

**ACCOMPLISHMENTS:** In FY99, the project completed the van-mounted measurement activities. The radar was assembled, upgraded and tested. Installation of a variable elevation angle antenna system was completed and tested. The antenna system consists of a high voltage transmit horn with a built-in third harmonic suppression filter and two receive horns; one for the fundamental band and one for the third harmonic band. An upgraded fundamental receiver had been assembled for side-by-side (fundamental and third harmonic band) SAR imaging.

**TRANSITION:** The technology developed under this project will transition to users at active test and training ranges, Base Realignment and Closure (BRAC) and formerly used defense (FUD) sites, and numerous foreign countries requiring advanced technologies for locating UXO.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Using Mode of Action to Assess Health Risks from Mixtures of Chemical/Physical Agents; CU-1073

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Richard Bull; Pacific Northwest National Laboratory – Richland, WA

**FY 2000 FUNDS:** $260K

**DESCRIPTION:** Mixtures of carcinogenic chemicals in groundwater plumes and soils are a major problem for Department of Defense (DoD) and Department of Energy (DOE) facilities. While there is frequently data available for interactions between chemicals to judge risks from short term exposures, data that describes how interactions influence the development of cancer are very rare. This is largely because of the high costs associated with conducting complex interaction studies over the lifetime of experimental animals. Therefore, it is important that the limited resources that are available for studying interactions be directed towards the development of general principles that can be applied to a wide variety of circumstances.

The hypothesis this project intends to test is whether classifying the modes of action represented in a mixture and knowledge about the dose-response characteristics involved in eliciting a particular mode of action will provide a simpler and more accurate means of predicting the hazards that the mixture poses over a range of exposure situations. Whereas the number of chemicals present in the mixture may be large, the number of modes of action responsible for these effects are small. Each mode of action may have dozens of mechanisms that might contribute to changes in cell birth/death processes, but establishing mechanisms for every chemical is very expensive. The modes of action represented by the three chemicals proposed for study are general to chemical carcinogenesis. Thus, the approach that would result from proving the project hypothesis should be broadly applicable to any mixtures of chemical and/or physical causes of cancer. The top seven chlorinated hydrocarbon solvents found on DOE facilities produce liver cancer by non-genotoxic mechanisms. Two others are clearly genotoxic. Therefore, all modes of action are represented among these compounds. The occurrence of the genotoxic compounds is much less frequent and generally at much lower concentrations than the first seven compounds. Their cleanup levels are less controversial because it is difficult to refute low dose linearity in response for such chemicals and their concentrations rarely exceed drinking water standards of the Environmental Protection Agency (EPA).

**BENEFIT:** Because of the high cost associated with conducting research to examine biological interactions, the study of every potential interaction of environmental concern is not feasible. This research is directed towards the development of general principles that can be applied to a wide variety of circumstances. The benefits to DOE and DoD from the work proposed are: (1) data bases that can be directly used to assess the risks from mixed exposures to DCA or TCA whether they arise as metabolites from a single solvent [e.g., Trichloroethylene (TCE)] or from a mixture of solvents, (2) the data necessary to see how these metabolites interact with a cytotoxic solvent (carbon tetrachloride), and (3) a test of the hypothesis that hazards associated with mixtures of carcinogenic chemicals can be addressed by simply identifying the mode of action and knowing the dose-response relationships for the individual chemicals.

**ACCOMPLISHMENTS:** In FY99 the project completed the Initiation/Promotion Studies. In-life studies were completed of the interaction of carbon tetrachloride, dichloroacetic acid and trichloroacetic acid in vinyl carbamate initiated B6C3F1 mice. The mice were treated with a single dose of vinyl carbamate at 2 weeks of age and given dichloroacetic acid and trichloroacetic acid in the drinking water or carbon tetrachloride via gavage (singly or in combination) for either 18, 24, 30 or 36 months. At the end of the study, the mice were killed and liver lesions were tallied and fixed for later evaluation. Tumor data are now being analyzed and slides are being prepared for selective histoevaluation. The pharmacokinetic studies being conducted at Wright Patterson Air Force Base (WPAFB) were also continued. In these studies, male B6C3F1 mice (n=4/dose/time point) were given a single oral dose of one of the following solvents in corn

oil: 1,1-dichloroethane- 1800 mg/kg, 1,1,2-trichloroethane- 300 mg/kg, tetrachloroethylene- 900 mg/kg, 1,1,1,2-tetrachloroethane- 200 mg/kg, cis- 1,2,dichloroethylene- 2000 mg/kg. The animals were sacrificed at 1 and 2 hr post dose, and whole blood and liver were taken. A second set of animals was exposed by the same method to a subset of the solvents and plasma only was taken. Blood, liver and plasma were analyzed by gas chromatography (GC) for dichloroacetic acid (DCA) and trichloroacetic acid (TCA) after derivitization and extraction. After determining which solvents produced DCA and TCA, in vitro experiments were done to investigate the inhibition of DCA metabolism in mice pre-exposed to DCA. Male B6C3F1 mice were placed on treated drinking water for 14 days at dose levels of 0.08, 0.8 and 2.0 g/L DCA (n=5/dose level). At the end of 14 days, animals were sacrificed and blood and liver were removed and stored at -80°C. DCA concentrations were determined by GC after derivitization and extraction. Data was plotted on a Lineweaver-Burke plot to determine kinetic constants. Evidence of inhibition was seen in the pre-dosed animals when compared to the control. The Km for control, 0.08, 0.8, and 2.0 g/l were 307, 139, 26, and 6.6 nmole, respectively. The respective Vmax values were 7.5, 3.0, 0.39 and 0.43 nmol/min/mg protein.

**TRANSITION:** The project has a transition plan that includes: (1) insuring utilization of the data through extensive interaction with EPA; (2) establishing the hypothesis that interactions between environmental carcinogens can be understood on the basis of their individual modes of action; and (3) expanding the concept to other important environmental mixtures.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Value-Added Site Monitoring & Infrastructure Maintenance for In-Situ Bioremediation; CU-1080

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Michael Barcelona; University of Michigan, National Center for Integrated Bioremediation Research & Development – Oscoda, MI

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** The objectives of this project included: the continued serial monitoring of intrinsic bioremediation processes at three fuel and solvent contaminated sites at the former Wurtsmith Air Force Base; the support, maintenance, and supplementation of the data in a relational database management system (RDBMS); and the statistical analysis of the data for spatial and temporal variability, estimates of mass removal rates and indicators of bioremediation process change.

The technical approach consists of a phased approach to the objectives outlined above. State of the art contaminant and geochemical ground-water monitoring was continued on a quarterly basis at three fuel and solvent contamination sites which have distinct oxidation-reduction zones. Indicators of corresponding bioremediation indicators and the mass of contaminants associated with aquifer solids was determined as well. Additional, statistical analyses of the time-series and spatial distribution of contaminants and geochemical conditions was evaluated for sources of error and variability. Bioremediation performance indicators was developed in selected oxidation-reduction zones. Several years of data exist for the three study sites which will provide a basis for the use of RDBMS and results of the statistical analyses by leading bioremediation modeling and remedial design groups.

**BENEFIT:** The project will provide direct benefit to Department of Defense (DoD), Department of Energy (DOE), and Environmental Protection Agency (EPA) by: (1) providing comprehensive field data for intrinsic remediation modeling efforts; (2) allowing more cost effective long term monitoring designs to be developed; and (3) improving basis for collaboration among technology developers which will mean less redundancy between efforts. An overall benefit will be more cost-effective designs and performance goals for bioremediation of contaminated sites.

**ACCOMPLISHMENTS:** Internet (internal) and an external web pages have been established. Field data has been updated and made more accessible. Laboratory and associated QA/QC data was completed. Presentations and poster sessions on data quality, petroleum hydrocarbon source strength estimates, and temporal variability of bioremediation indicators have been made. Peer-reviewed papers have been drafted on the latter issues. Permission was granted to proceed with the second tracer test.

**TRANSITION:** The results of the continued serial monitoring of intrinsic bioremediation processes will be made widely available to facilitate transition of the project's efforts. The various efforts to ensure dissemination of information will enable further usage by DoD and DOE site managers.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Genosensor-Based Ecotoxicity Response Assessment; CU-1081

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Kenneth Beattie; Oak Ridge National Laboratory – Oak Ridge, TN

**FY 2000 FUNDS:** $850K

**DESCRIPTION:** The objective of this project is to develop cost effective methods and instrumentation for directly monitoring genotoxic exposure in a variety of natural ecosystems. Direct measurements of the in-situ biological responses associated with genotoxic exposure of sentinel species in the environment circumvents the difficult problem of bioavailability, since measurable molecular endpoints in resident species are a direct reflection of ecologically relevant exposure. The project intends to implement emerging biochip technology for in-situ monitoring of molecular endpoints of genotoxic exposure, including Deoxyribonucleic Acid (DNA) damage-inducible gene expression pathways, in soil and water ecosystems.

This project intends to employ novel channel glass biosensor chips containing arrays of DNA probes to characterize and monitor the response of soil microorganisms to exposure to genotoxic agents. The biochip device consists of a glass or silicon dioxide wafer containing miniature patches of densely packed pores of 1-10 μm diam., extending through and perpendicular to the wafer surface. DNA probes can be immobilized within individual porous patches at addressable sites across the wafer, to provide a microscopic array of unique nucleic acid hybridization sites. An array of surface-tethered oligonucleotide probes is called a genosensor. The technical objectives of the project will be achieved via the following specific tasks: (1) fabricate channel glass genosensor arrays containing DNA probes specific to currently known bacterial stress response and DNA damage-inducible genes; (2) use the "stress response genosensor" to characterize the induction of known stress genes in model soil bacteria exposed in the laboratory to various genotoxic chemicals; (3) utilize a new genosensor- based oligonucleotide fingerprinting strategy to discover new stress response/DNA damage inducible genes; and (4) initiate ecotoxicity surveillance studies with soil and water samples from DOE and DoD sites. The main technical challenges associated with the project include the requirement to extract intact (undegraded) RNA from environmental samples and the low abundance of soil microorganisms deep below the surface. Feasibility studies will directly address these critical issues in order to define the operational limitations and utility of the approach.

**BENEFIT:** Expanded capabilities for ecotoxicity surveillance that incorporate a comprehensive collection of molecular endpoints associated with military-relevant compounds would greatly facilitate site characterization, risk assessment and monitoring of the progress of remediation efforts at Department of Defense (DoD) and Department of Energy (DOE) installations. Such capabilities for rapid, multispecies biological endpoint monitoring that is ecologically relevant to cleanup of contaminated sites, should provide a rational basis for reduced cleanup costs, addressing the "how clean is clean?" question. The new technology is expected to enable site closures in a shorter period of time, bringing significant long term cost savings.

**ACCOMPLISHMENTS:** In FY99, an experimental system was established at the U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC), Environmental Laboratory for monitoring the expression of several "indicator genes" (known to be induced in response to genotoxic exposure) in three microbial species treated with military-relevant toxic compounds (components of explosives and fuels): the reduced nicotinamide adenine dinucleotide phosphate (NADPH)-dependent nitroreductase in Escherichia coli, the toluene dioxygenase gene in Pseudomonas putida, and the alkane dehydrogenase gene in Pseudomonas oleovorans. DNA and Ribonucleic Acid (RNA) were extracted from cells cultured in the absence and presence of toxic compound, and reverse transcriptase-polymerase chain reaction (RT-PCR) was carried out to amplify specific regions sequences within the Messenger Ribonucleic Acid (mRNA) encoded by the indicator genes. Gel electrophoretic analysis was used to visualize the increased expression

of indicator genes in the presence of toxic compound. The nucleic acid samples prepared in this study are essential for the upcoming validation of the genosensor technology for ecotoxicity response assessment.

**TRANSITION:** The project intends to transition through to the Environmental Security Technology Certification Program (ESTCP) for validation. The long term aim of the project is to install and operate genosensor systems at Oak Ridge National Laboratory (ORNL) and ERDC for use in assessing ecological effects of genotoxic exposure at DOE and DoD sites.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Negative Ion Sensors for Real-Time Downhole DNAPLs Detection; CU-1089

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Gregory Gillispie; Dakota Technologies, Inc. – Fargo, ND

**FY 2000 FUNDS:** $370K

**DESCRIPTION:** Location of the DNAPL sources and reliable estimates of their masses are crucial for cost-effective cleanup. No currently available method can accurately and efficiently define the subsurface distribution of chlorinated solvent DNAPLs. The objective of this project is to develop a Site Characterization and Analysis Penetrometer System (SCAPS) probe which can detect, locate, quantify, and determine the subsurface distribution of Dense Non-Aqueous Phase Liquids (DNAPLs) in the soil. The key probe elements are a heated membrane interface and a sensitive, fast-responding downhole detector. Performance objectives have been established as follows: sensor responsiveness to all common organochlorine compounds, vapor limit of detection of 1 ppmv, selectivity better than 5000:1 relative to fuel hydrocarbons, less than 3 second response time, and automatic operation as the probe is advanced by a cone penetrometer or Geoprobe.

The research objectives are to characterize the existing Polytetrafluoroethylene (PTFE) membrane's time-and temperature-dependent permeability for chlorinated solvents, fuel hydrocarbons, water, and oxygen; identify, select, and evaluate promising alternative membrane materials; find the material transfer efficiency as a function of distance from the membrane, soil type, temperature, and moisture; and optimize sensor performance, reliability, and ease of operation. Three sensor approaches which exploit the high electronegativity of chlorinated compounds have been identified. They are thermionic ionization sources, a photoemissive electron capture detector (PE-ECD), and a photoemissive ion mobility spectrometer (PE-IMS). The former two will be investigated in this effort. Risk is relatively low because the heated membrane is already in commercial use and preliminary laboratory data have been acquired for the sensors.

**BENEFIT:** Using today's technology, the cost to remediate Department of Defense (DoD) sites alone is estimated at $35B. Annual costs greater than $500K for containment and monitoring a single DNAPL plume are typical. If successful, the sensors developed in this project will provide more cost-effect remediation owing to improved spatial resolution for delineation of DNAPLs source terms, lower sensor acquisition and operating costs, and sensor compatibility with other chemical and physical sensors. Subsidiary benefits include an improved membrane interface for all types of volatile organic compound (VOC) analysis (uphole or downhole).

**ACCOMPLISHMENTS:** In FY99, the principal thrust has been refining the downhole Halogen Specific Detector (XSD) and Photoionization Detector (PID) to improve reliability of field operation. The XSD and PID studies are following parallel tracks, but with considerable crossover between them. The sensor element in each case generates small continuous currents on the order of nanoamps. The current must be converted to a voltage before the signal is logged in the data acquisition system. Initial field studies showed the need to prevent any water and mud that leaks through the Geoprobe push rods from coming in contact with the sensor. Also found was that stresses and torques on the umbilical cord during normal rod handling leads to extraneous background noise. The project team has capped the XSD assembly with a 4-inch section embedded with Kevlar-reinforced elastomer, which both waterproofs the sensor and firmly anchors the umbilical cord. Both sensors benefit from water management (i.e., removal of the water vapor passed by the membrane interface probe) and currently are not susceptible to noise signals arising from cable twisting and vibrations.

**TRANSITION:** The project intends to transition through to the Environmental Security Technology Certification Program (ESTCP) for a full scale demonstration/validation in cooperation with Air Force Center for Environmental Excellence (AFCEE) and Environmental Protection Agency (EPA)-Ada, OK. The researchers also have identified the potential for licencing the sensor technology through a third party.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Integrated Geophysical Detection of DNAPL Source Zones; CU-1090

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Robert Grimm; Blackhawk Geometrics, Inc. – Golden, CO

**FY 2000 FUNDS:** $445K

**DESCRIPTION:** The objective of this project is to provide cost-effective three-dimensional (3-D) geophysical imaging of the geological control on Dense Non-Aqueous Phase Liquid (DNAPL) distribution and migration at different spatial resolutions and, at the highest available resolution, to directly image DNAPL. Specifically, the project intends to develop a three-fold approach to characterization of physical heterogeneity controlling DNAPL migration and the ultimate imaging of DNAPL distribution in the subsurface: (1) joint 3-D tomographic inversion of surface seismic refraction and electrical resistivity data to broadly delineate subsurface geology; (2) high-resolution joint 2-D/3-D crosshole tomography using downhole seismic and electrical sources and sensors in permanent 4-inch wells and/or temporary 2-inch boring; and (3) utilization of the same downhole electrical sensors to perform IP tomography to image DNAPL with the geological constraints from the above two steps. This three-fold approach will provide new cost-effective, minimally invasive technologies for 3-D geophysical imaging of DNAPL without producing any secondary waste.

**BENEFIT:** The results of this research development will include computer software, downhole seismic, and electrical instruments, and case histories focused on Department of Defense (DoD)/Department of Energy (DOE) sites. The direct benefit of this integrated package is the unique capability to produce high-resolution 3-D images of geological structures and DNAPLs in the subsurface. Collecting field data and conducting 3-D computer tomographic imaging for monitoring DNAPL migration can be completed in real time. When this approach becomes available, it can facilitate the design of new treatment/remediation technologies. Based on the image of DNAPL distribution and its geological controls, it can also help improve risk assessment and estimate the realistic cost for remediation alternatives. Collecting 3-D surface seismic and electrical data may take 2 days. Downhole seismic and direct current (DC) resistivity measurements may take 1 day. Downhole IP measurements need only a few hours.

**ACCOMPLISHMENTS:** In FY99, the project performed a two-dimensional joint tomography field test at the Department of Energy's (DOE) Savannah River Site, developed 3-D complex-resistivity tomography software, acquired software for 3D seismic-refraction tomography, acquired a geophone string that can be used in a small-diameter cone-penetrometer (CPT) well, partially developed the seismic source that will be used in conjunction with the CPT, assessed two complex-resistivity measurement systems in the lab, performed laboratory tests of the nonlinear continuum regression (NLCR) response of soil samples from 4 DOE/DoD sites to DNAPL, and performed a field test of NLCR at the former DOE Pinellas Site.

**TRANSITION:** Providing a successful initial proof-of-concept study, the project has a transition plan that includes the possible integration with existing systems such as SCAPS to apply the technology developed. Other potential users of the three-dimensional geophysical imaging of DNAPL distribution and migration include: the Air Force Research Lab, Sandia National Lab, and Lawrence Berkeley National Lab.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Innovative Seismic System for Buried Unexploded Ordnance Detection and Classification; CU-1091

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Peter Krumhansl; BBN Systems and Technologies – Cambridge, MA

**FY 2000 FUNDS:** $585K

**DESCRIPTION:** The objective of this effort is to investigate and develop a new Seismic Ordnance Detection System (SODS), which can improve the discrimination of unexploded ordnance (UXO) from clutter and thus reduce the number of excavations required during cleanup. The new seismic sensor will sense the mechanical properties of buried objects rather than their magnetic or electrical properties. The SODS system will operate in a manner similar to an active sonar system, with a mobile seismic array which sends broadband vibrational energy into the ground. These waves when they encounter an object with anomalous mechanical properties cause the object to rotate, translate, and to "ring," scattering energy back to the surface. These echoes will be received by an array of geophones and digitally recorded. The received signals are beamformed to locate the objects and to analyze the characteristic echo from the object. These characteristic echoes when used in conjunction with the magnetic and electrical response will more efficiently differentiate UXO from inert objects. After development and characterization of the performance of SODS, it can be used as one of a suite of sensors that can be tailored to specific site conditions and UXO types. This will significantly reduce survey and cleanup costs, especially in areas with high metal clutter or environmental degradation of the performance of other sensors.

The technical approach for the investigation and development of the SODS consists of: (1) performance of an initial feasibility study to analyze the practicality of seismic UXO detection using short wavelength shear waves; (2) development of a proof-of-concept SODS for testing; and (3) evaluation of the proof-of-concept SODS in controlled testing. The system simulation of SODS will be based on computer modeling and field measurements of seismic wave propagation and noise. The second phase will utilize seismic sources and receivers that provide greater bandwidth, increased source level, and better earth coupling than are commercially available while engineering a practical mobile array of seismic transducers that can be used to efficiently collect seismic data. The third phase will include refining of the proof-of-concept system through diagnostic tests and analyzing detections of UXO culminating in an initial evaluation of SODS in multi-sensor tests and an analysis of false alarm reduction using the seismic data in a sensor fusion process.

**BENEFIT:** The project intends to provide to SERDP: (1) a fully developed SODS that will significantly improve the accuracy of UXO site characterization and reduce excavations and cleanup costs; (2) a SODS that will provide UXO detection and classification capabilities in environments where other sensors perform poorly; and (3) a SODS that will detect non-metallic ordnance and other buried wastes or structures.

**ACCOMPLISHMENTS:** In FY99 the project developed a 2 ½ D elastic finite element target response modeling capability for axisymetric objects. This new tool can be used to model realistic ordnance items and examine them for characteristic resonances and estimate target strength. The code is being further validated with test cases. The project also developed analytic models for shear wave target strength of simple spheres. The project has performed seismic field tests in order to quantify seismic propagation parameters. These included compressional, shear, and Rayleigh wave speed, attenuation, path coherence, ambient noise and reverberation. The project began integration of seismic sources, seismic sensors, and instrumentation in preparation for component evaluations and detection tests. This system will evaluate the critical technologies for a practical system and be used to do controlled testing of UXO seismic response.

**TRANSITION:** The project intends to transition through to the Environmental Security Technology Certification Program (ESTCP) to develop a fieldable Seismic Ordnance Detection System prototype.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Model-Based Data Fusion and Discrimination of UXO in Magnetometry and EM Surveys; CU-1092

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. J.R. McDonald; Naval Research Laboratory – Washington, DC

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** The objective of this project is the development of data fusion techniques for the best available existing sensor suites, to better allow discrimination between intact ordnance and the typical clutter associated with target and bombing ranges. Specifically, Naval Research Laboratory (NRL) intends to develop software techniques to allow discrimination of intact ordnance from Ordnance Explosive Wastes (OEW) using arrays of full-field magnetometers and time-domain electromagnetic sensors as the primary detection tools. These goals will be accomplished by developing new software for target identification, physical modeling, and probablilistic classification that uses the sensor data sets jointly. NRL's Multi-Sensor Towed Array Detector System (MTADS) will be the primary platform for which the software will be designed, although the work is applicable to any magnetic and electromagnetic array measurements and some aspects of the development are relevant to other types of sensor data.

**BENEFIT:** When integrated into an operational unexploded ordnance (UXO) survey system such as MTADS, this data analysis system will reduce target analysis time by up to 50 percent. Location information, including position, size and depth, is expected to also be mildly improved. The major benefit of this analysis will be a significantly improved ability to differentiate UXO from OEW and other clutter. An improvement in false alarm levels of a factor of two will reduce ordnance remediation costs by 50 percent at most sites. The probabilistic approach used by the network classifier will provide statistical information that will be important for Quality Assurance/Quality Control (QA/QC) site analysis and for risk-based cost benefit analyses.

**ACCOMPLISHMENTS:** The discrimination of ordnance from ordnance scrap items and other clutter for three different locations was performed using the probabilistic neural network (PNN). After evaluating the initial classification results, the data sets were characterized and several strategies were investigated to improve the performance of the PNN on these data sets. This study has demonstrated that it is possible to use the outputs from a physics-based modeler (magnetometry data only) for training a PNN to discriminate UXO from scrap. As expected, classification performance was found to be data set dependent. The PNN classification performance tracked the visual clustering of the data seen using principal component analysis and nonlinear mapping (i.e., good clustering = good classification performance). Model outputs from Badlands Bombing Range (BBR) 2 were used to train a PNN model, which could correctly discriminate UXO from scrap at the BBR1 location. The exact cause for many of the misclassified UXO could not be determined from the results in this study, although most of the misclassifications occurred for small ordnance. The model outputs for the misclassified objects were much different than the outputs for the others in that UXO class. Further improvements in the model or the use of data fusion of MAG and EM responses must be made in order for classification results to improve.

**TRANSITION:** The project has a transition plan that includes: (1) integration of the new analysis system into the MTADS for evaluation; (2) transition of the project to the Environmental Security Technology Certification Program (ESTCP) for demonstration/validation at a live-fire range; and (3) eventual transition of the current MTADS to the commercial sector.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** In-Situ Clay Formation: A New Technology for Stable Containment Barriers; CU-1093

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Joanne Fredrich; Sandia National Laboratory – Albuquerque, NM

**FY 2000 FUNDS:** $400K

**DESCRIPTION:** A new type of containment barrier with a potentially broader range of environmental stability and longevity could result in significant cost-savings to the Department of Defense (DoD) and Department of Energy (DOE). This project intends to precipitate clays in-situ in porous geologic materials by building on the technologies that exist for colloidal or gel stabilization. Unlike colloidal or gel barriers, however, a precipitated-clay barrier does not require saturated conditions to be functional. Thus, it can be emplaced without loss of performance in the vadose zone as well as areas with fluctuating water tables. Clays have the advantage of being geologically compatible with the near-surface environment and naturally sorptive for a range of contaminants. The precipitation of clays in-situ in soils and sediments should result in (1) reduced permeability and hydraulic conductivity and (2) increased mechanical stability through cementation of soil particles. By analogy with natural diagenesis in sedimentary rocks, the researchers intend to engineer "artificial" lithification in soils and sediments. Unlike natural diagenesis, however, the time-scale for clay growth will be accelerated greatly from more than tens of thousands of years down to a few weeks.

The technical approach is multidisciplinary and involves the following: (1) confirm published results suggesting that clays can be precipitated in a few weeks to months from aqueous gels; (2) design an optimal gel composition that will maximize clay yield and crystallization rate, while maintaining injectability into porous soils and sediments; (3) test the barrier formulation in laboratory experiments; and (4) test the method in a field experiment. The critical key step in developing the new barrier technology will be to successfully optimize the formation of clays from aqueous gels under ambient conditions. Therefore the first year of the project will be focused on this step. However, researchers will also initiate the laboratory experiments and measurements (flow properties and mechanical stability) in order to address technical details that may arise with the materials or experimental design. Gel composition will be designed using approaches taken from the literature involving reactions and additives known to accelerate clay formation. Emphasis will be placed on characterizing the clay with respect to quantity, composition, and crystallinity. Emplacement of gels in laboratory tests will emulate field technologies such as permeation and jet grouting, and soil-mixing.

**BENEFIT:** The results from this project will yield a new barrier technology that potentially has a broader range of mechanical and chemical stability and therefore, can be applied in a broader range of environments ranging from arid to humid, and to specific contaminants, ranging from Dense Non-Aqueous Phase Liquids (DNAPLs) to metals. DoD and DOE cleanup sites are located in a wide range of environments across the country and have a range of contaminants. The new barrier technology should also possess greater longevity requiring less maintenance over the longterm and less risk of remediation due to barrier failure or leakage. Total cleanup costs to the DoD and DOE should be substantially reduced due to the longer lifetime of the barrier. Once developed, it is anticipated that the implementation cost of the new barrier technology should be on the order of the least expensive chemical grouting technologies currently available.

**ACCOMPLISHMENTS:** In FY99 the team has synthesized clay (kaolinite) and clay-like solids (hydrotalcite and mesoporous silicates) in the laboratory under ambient conditions in less than several weeks. The general optimal solution compositions from which these solids can be precipitated have been identified. Measurement of the chemical stabilities of all three types of materials has been initiated. The sorption capacity of the mesoporous silicates for hydrophobic organic compounds in aqueous solutions has been determined and found to be similar to that of organo-intercalated smectite clays. Nucleation of clays in

quartz grain surfaces has been determined to occur within less than one week under ambient conditions. One manuscript is in press, one submitted, and an abstract was presented at the fall 1999 meeting of the American Chemical Society.

**TRANSITION:** The project has a transition plan that includes: (1) full-scale demonstration of the clay formation technology at a DoD site; (2) pursuit of cooperation with industry and consortia (i.e., Remediation Technologies Development Forum); and (3) direct sharing of information on the methodology to DoD and DOE installation managers.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Environmental Impacts to the Chemical Signature Emanating from Buried UXO; CU-1094

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. James Phelan; Sandia National Laboratory – Albuquerque, NM

**FY 2000 FUNDS:** $98K

**DESCRIPTION:** The objective of this project is to develop a validated subsurface transport model that can be used to predict the spatial and phase specific concentration of chemical signature molecules derived from shallow unexploded ordnance (UXO) under the influence of specific environmental conditions. Other government programs are developing chemical detector platforms that can provide a separate unique signal to classify subsurface objects identified with existing geophysical systems. It is estimated that eleven million acres of land needs assessment to identify subsurface UXO - with costs estimated to be about $1.4M/acre. The ranges where UXO can be found are distributed throughout the country where environmental conditions vary significantly. It is the hypothesis of this project that these environmental conditions will have a significant impact on the transport of chemical signature molecules from subsurface UXO to the surface before presentation to a chemical detector system. It is planned that through system analysis, team members can show the ranges and/or combination of environmental parameters that improve or constrain the transport of chemical signature molecules to the chemical detector system. This analysis will enable end users to better understand the merits and limitations when looking to deploy this chemical detector technology.

The first task is to perform a sensitivity analysis of known input parameters in a one-dimensional analytical contaminant transport model, expand this model to assess two-dimensions to explore the surface area footprint from buried UXO, and modify an existing numerical simulation code (T2VOC) (precipitation/evaporation, temperature cycling, liquid diffusion) for use as the complete systems analysis tool. Inverse modeling will be used to assess input parameter sensitivity and as a tool for the design of laboratory validation experiments in task three. Task two involves the measurement of specific transport parameters currently not available in the literature for explosive signature molecules. These include temperature dependent water solubility, vapor-solid sorption as a function of soil moisture content and source-term emission rates. Task three will be a laboratory validation study that will confirm the most critical parameters included in the simulation model. Task four will utilize this validated model to assess the impacts of environmental conditions on the transport of chemical signature molecules from shallow UXO and support end - user queries on the utility of chemical sensor platforms for the classification stage in the identification of true unexploded ordnance.

**BENEFIT:** This project will provide Department of Defense (DoD) with a new tool to assess the functionality of chemical detector platforms in service to classify shallow UXO from non-UXO. Use of the model, simulations, and systems analysis will improve the decisions made on the utility of chemical detector platforms in a variety of environmental conditions that are expected to have an important role in the transport of chemical signature molecules from shallow UXO. If chemical detector platforms can meet the performance requirements for many application sites, a substantial savings can be expected in reducing the number of non-UXO items treated as UXO during range cleanup activities.

**ACCOMPLISHMENTS:** In FY99 the project team had accomplishments in two areas:

***Lab-Scale Experiments:*** The plenum on top of the soil column was used in a series of calibration tests to measure the collection efficiency of the Solid-Phase Microextraction (SPME) fiber under dynamic conditions. It was found to collect about 1.5% of the mass of Dinitrotoluene (DNT) compared to tenax. This will give optimum sampling compared to other methods. The TDR soil moisture probes were calibrated against gravimetric moisture measurement. The porous plate matric suction assembly was arranged such

that evaporative losses of water through the soil and into the plenum could be measured. Simulation runs with Trinitrotoluene (TNT) were completed to determine what initial conditions to use, including the mass flux of DNT into the soil column. Soil column tests were expected to start in October 1999.

***UXO Chemical Signature Field Characterization:*** The project team contacted the appropriate personnel to request access to Southwest Proving Ground in Hope, Arkansas. Team members were put into contact with American Technologies, Inc. who is executing the field operation to provide ground truth of mag/flag operations. The project will contract with ATI to provide field soil collection services at the locations planned for excavation of the UXO item.

**TRANSITION:** The project has a transition plan that includes: (1) sharing performance targets directly with developers of commercial chemical detector systems; (2) making available operational strategy information to end-users; and (3) pursuing advancement of the chemical detector platform through a demonstration/validation field testing program, such as the Environmental Security Technology Certification Program (ESTCP) or the U.S. Army Night Vision Lab.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Assessment and Prediction of Biostabilization of Polycyclic Aromatic Hydrocarbons (PAH) in Sediments; CU-1095

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Jeffrey W. Talley; U.S. Army Corps of Engineers Engineer Research and Development Center, Environmental Laboratory – Vicksburg, MS

**FY 2000 FUNDS:** $500K

**DESCRIPTION:** The objectives of this research are to identify those factors affecting biostablization of Polycyclic Aromatic Hydrocarbons (PAH) in sediments and to develop the technical basis for enhancing natural recovery processes for the biotreatment of PAHs in dredged material. The key questions to be addressed in this research are: (1) Where exactly at the microscopic scale do PAHs reside on aged sediments?; (2) How are the microscopic-scale locations of PAHs on sediments dependent on sorbent carbon location and type?; (3) What are the distribution of binding activation energies for desorption of PAHs from sediment particles, and how does this correlate with information on PAH association with sorbent carbon type?; (4) How does the effectiveness of bioslurry treatment of dredged sediments depend on the locations and associations of PAHs with sorbent organic matter and distributions of binding activation energies with respect to removal of specific compounds, the fraction of labile and resistant PAHs, and the toxicity of residual PAHs?; and (5) How may knowledge of the association of PAHs with sorbent carbon type and location, and distribution of binding activation energies, be used to assess and predict the overall performance of bioslurry processes for biostablization of PAHs? This research will assess the fundamental character of the binding of PAHs at the microscopic scale in parallel with bioslurry treatment and ecotoxicological testing, to show how the nature of PAH association with sediments related to biostablization, achievable treatment endpoints, toxicity, and bioavailability. The work will explore mechanisms controlling PAH sequestration using novel spectroscopic techniques to examine at the microscale the distributions and associations, and binding energies of PAHs in sediments.

**BENEFIT:** The potential benefits of this research include: reduced treatment costs, improved evaluation and design for clean-up technologies, greater regulatory and public acceptance of biostablization, increase in the reuse/recovery opportunities for treated contaminated dredged materials, and potential application for in-capped sediments.

**ACCOMPLISHMENTS:** In FY99 researchers have performed PAH analysis on size and density separated samples of Milwaukee Confined Disposal Facilities (CDF). The CDF sediment was used to evaluate the relative abundance of PAHs in the various bulk components found within the sediment. Analysis of the sediment found that coal and wood derived particles contained most of the PAHs in the sediment. Researchers found that clays release PAHs much faster than coal and wood derived particles thus providing evidence that suggests coal and wood are major PAH sorber's. Currently solid phase desorption experiments are being conducted to study PAH desorption kinetics using size and density separated Milwaukee CDF sediment components.

**TRANSITION:** The project has a transition plan that includes dissemination of results through established scientific communications channels, as well as proposed partnering efforts with the Army Research Office and the Gas Research Institute.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Processing Techniques for Discrimination between Buried Unexploded Ordnance and Clutter Using Multisensor Array Data; CU-1121

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Thomas Bell; AETC, Inc. – Arlington, VA

**FY 2000 FUNDS:** $401K

**DESCRIPTION:** The objective of this project is to develop a reliable technique for discriminating between buried UXO and clutter using multisensor electromagnetic induction sensor array data. The effort builds on existing research which exploits differences in shape between ordnance and clutter to include the effects of other distinctive properties of ordnance items (fuze bodies, driving bands, fin assemblies, etc.).

Specifically, the project intends to perform tests in the less than 100 KHz domain. The effort will develop: (1) models for the ordnance signature and its constituent parts; (2) procedures for determining target characteristics from multisensor data using the signature models; and (3) decision rules for discriminating between buried UXO and clutter.

**BENEFIT:** The product of this research is primarily processing algorithms and procedures for using existing sensor technology within the less than 100 KHz domain.

**ACCOMPLISHMENTS:** In FY99 the project team has have made progress in three areas: (1) calibrating and evaluating the broadband electromagnetic sensor, GEM3, (2) evaluating the information content of data from the GEM3, and (3) developing a baseline model for Electromagnetic Induction (EMI) response from simple shapes.

***Evaluating the GEM3:*** The project team has evaluated the accuracy and repeatability of the GEM3 instrument with a thorough calibration against metal spheres, ferrite rods, and wire coils. They found frequency-dependent errors in the phase and amplitude of the GEM3 signal and defined curves to correct them. After this correction, the researchers found very good agreement between the GEM3 data and the analytical models for spheres and coils. The team determined that the background signal when no target is present drifts significantly, and that this had been causing errors in the data. Team members addressed this by instigating new data gathering procedures and background interpolation, dramatically improving accuracy and repeatability of the instrument. Geophex is currently working on a next generation version of the GEM3 which is expected to be much less susceptible to background fluctuations. Team members also found that carefully leveling the instrument and centering the sample under the coil using a plumb line are required for collecting good test data. These steps are now part of the data collection procedure.

***Evaluating Information Content:*** The project team collected data on a range of simple targets (spheres and cylinders) as well as ordnance items over several depths and orientations. From these data they determined effects due to depth, temperature, heterogeneous composition, or surface condition are about 1%, while the signal varied by 10% or more between objects. This variation is repeatable and has non-trivial structure from object to object, confirming that the data contains significant object-specific information.

***Development of the General Model:*** A general model based on the analytic solutions for spheres and horizontal infinite cylinders was developed, which fits a wide variety of objects surprisingly well. This model stems from the observation that for high values of relative permeability, the sphere model S, and horizontal infinite cylinder model C, can be related by $C = 2/3 * S + 1/3$. The general model G is patterned after this relationship: $G = a * S + b$. Coefficients 'a' and 'b' are derived from formulas for asymptotic values at high and low frequencies. In terms of the relative permeability 'mu' and demagnetization factor 'n' of the object, they are: a = 2*(2+mu)/(9*(n-1)*(1+n*(mu-1))) b = 2*(mu-1)(3*n-1)/(9*(n-1)*(1+n*(mu-

1))). Fortunately, parameters for this model are physical quantities which can be found in the literature. Demagnetization factors derived from fitting to GEM3 data agreed well in most cases with published values.

**TRANSITION:** Primary products are ability to optimize EMI sensor array configuration and effective processing algorithms for EMI data. These may be directly transitioned to modify the MTADS platform and data analysis system. Introduce measurement techniques and processing algorithms in commercial survey work. The research effort also entails direct involvement with the user community.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** UXO Discrimination by Mid-Frequency Electromagnetic Induction; CU-1122

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Kevin O'Neill; U.S. Army Corps of Engineers Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory – Hanover, NH

**FY 2000 FUNDS:** $294K

**DESCRIPTION:** This project will perform basic research on sensor development, sensor utility, and signature possibilities in the uncharted 25 kHz – 300 kHz Medium Frequency - Electromagnetic Induction (MF-EMI) electromagnetic frequency band, for induction sensing of buried Unexploded Ordnance (UXO). The goal is to provide enhanced discrimination of ordnance from non-ordnance, and thereby reduce false alarm rates during field surveying. This will be accomplished by innovative instrumentation development in the MF-EMI band, in tandem with new modeling work.

Technical objectives for this project include: (1) Perform lab measurements of soil electrical properties, including seasonal effects, for samples relevant to UXO sites in order to quantify expected subsurface signal loss rates; (2) Extend and verify suite of computer programs to achieve rigorous 3-D solution of the physics of response by non-idealized UXO and non-UXO targets in realistic environments in this frequency range; (3) Produce high fidelity simulations in time, space, and frequency domains of the response by a wide range of specific UXO morphologies and dispositions, and by common non-UXO targets (fragment clusters, tin cans, open shapes, etc.) in realistic environments; (4) Obtain measured induction responses for array of UXO and non-UXO targets, using technology to be developed and exploiting existing data bases where possible; and (5) Use all of the above to identify distinctive UXO signature behaviors, and their discernibility relative to the environment, for combination with those being obtained in frequency ranges both above and below 25 KHz - 300 KHz.

**BENEFIT:** This work builds directly on recent progress in innovative EMI signature identification in the lower frequency EMI range (100 Hz – 25 kHz) and thereby amplifies its impact. As basic research it will not provide immediate answers, but is directed towards aiding in: (1) Substantial reduction of the false alarm rate in UXO field surveying; (2) Cheaper remediation of UXO hazard sites; (3) Faster and safer surveying of potential hazard sites; and (4) Computational and modeling tool development for wide range of related electromagnetic applications.

**ACCOMPLISHMENTS:** In FY99 the project focused on three areas: (1) developing the analytical models for different shapes, (2) developing the numerical modeling or arbitrary 3-D shapes, and (3) developing the instrumentation.

***Analytical Models:*** The team developed models over the entire (low and mid-) frequency range for spheres and spherical shells, solid and hollow long rods with axial and transverse excitation, prolate spheroid, and perfect reflectors.

***Numerical Models For Arbitrary 3-D Shapes:*** The project team conducted a comparison test of induction and radar responses from metallic perfect reflectors. The program for full electromagnetic penetration of a target is currently being tested.

***Instrumentation and Measurements:*** The research team has established that an instrument can be assembled from critical components that are now available commercially. The Team has developed a measurement scheme, in parallel with development of a "real" device, to drive a GEM-3 sensor head with

network analyzer to do "quick and dirty" measurements that should show distinctive effects in the MF-EMI regime.

**TRANSITION:** The project intends to transition through to the Environmental Security Technology Certification Program (ESTCP). Also, integration in basic research effort of industrial partner with wide experience in developing innovative instruments, followed by field testing, application, and ultimately commercial distribution.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Statistical Signal Processing with Physics-Based Models: Multi-Sensor UXO Detection and Identification; CU-1123

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Leslie M. Collins; Duke University – Durham, NC

**FY 2000 FUNDS:** $283K

**DESCRIPTION:** Several sensor modalities are currently being explored for the detection and identification of surface and buried unexploded ordnance (UXO). These include electromagnetic induction (EMI), magnetometers, radar, and seismic sensors. These sensors experience little difficulty detecting the UXO, thus detection does not create the bottleneck that results in the high cost of remediating sites. The primary contributor to the costs and time associated with remediating a UXO contaminated site is the high false-alarm rate associated with each of the sensors when operated individually. In this project, the team will investigate the phenomenological aspects of the UXO detection, location, and discrimination problem using EMI, radar, seismic, and magnetometer sensors. The fundamental insight garnered by characterizing the underlying physics will be transitioned into high-performance sensor fusion and signal-processing algorithms for enhanced detection, location, and discrimination of buried UXO under a wide range of environmental conditions.

The technical approach will employ synergistic research activities in modeling, signal processing, and sensor fusion. The researchers will perform phenomenological modeling of wave propagation and scattering for ultra-wideband (UWB) radar, seismic, and EMI sensors. The phenomenological studies will be performed in collaboration with SERDP-supported sensor-development programs underway in these areas (at NRL, ARL, and BBN). The previously developed models will be extended to allow arbitrary numbers of soil layers, arbitrary target shape and orientation, and to accurately account for all interactions. The use of these models will quantify the target types, depths, and soil conditions for which radar is an appropriate sensor. These models of the wave physics, coupled with models of target, clutter, and environmental uncertainties, will be incorporated into a statistical signal processing framework, thus novel, state-of-the-art optimal detection and identification algorithms will be developed for each sensor. Bayesian algorithms, which provide the optimal solution to detection and identification problems, will be investigated along with an algorithm based on a Hidden Markov Model formulation which is specifically suited for classification using data from multiple aspect angles. Finally, the researchers will develop sensor-fusion techniques that simultaneously exploit the richness and diversity of the phenomenology underlying multiple sensor modalities. Again, both Bayesian and Hidden Markov Model algorithms will be investigated. In all cases, the algorithms that are developed will be tested on data collected using sensor systems also under SERDP support, such as the BBN seismic sensor, Naval Research Laboratory (NRL)'s Multi-Sesnor Towed Array Detection System (MTADS), the Air Force Research Laboratory (ARL) Boom-SAR, and Geophex's GEM-3 EMI sensor.

**BENEFIT:** The goal of this project is to develop algorithms that substantially reduce false alarm rates associated with individual sensors, and that optimally combine information across sensors to further reduce the false alarm rate. Such reductions would dramatically decrease the time required to remediate Formerly Used Defense Sites (FUDS) and Base Realignment And Closure (BRAC) sites, thus decreasing the associated costs. One of the principal reasons for organizing cooperative agreements with ARL, NRL, and BBN is to assure the models and algorithms developed under the proposed research are transitioned as quickly as possible to the users in the field. It is felt that the collaborative relations will allow the researchers to tailor project developments such that they are of use to practical systems. Moreover, these organizations, which are responsible for hardware design and measurement campaigns, will gain insight from the phenomenological models to assure that the systems are designed and deployed in the most salutary fashion.

After each milestone is completed, the attendant software will be released to SERDP for all SERDP contractors to use.

**ACCOMPLISHMENTS:** The modeling work to date has focused on three sensors: magnetometer, time- and frequency-domain EMI, and Boom-SAR. The project team has applied a simple dipole model for magnetometer data to field data and have successfully used it to estimate target depth. Team members are currently investigating the utility of other parameters estimated with the model as target discriminants. The project has developed a full Method of Moment (MoM) model for predicting the fields recorded by EMI sensors as well as a simpler model that assumes that the induced magnetic fields can be characterized by a dipole. Team members are currently investigating the performance and limitations of the simpler model. For the Boom-SAR, the project has developed a multi-level fast-multipole algorithm for modeling radar scattering. The model results in considerable computational savings and has been compared favorably to measured radar data. One of the signal processing efforts has focused on applying statistical techniques to field data measured during the Jefferson Proving Ground (JPG)-IV experiment. This work has resulted in performance improvements over those obtained by the various vendors. This work has also shown the utility of fusing magnetometer and EMI data. The project team has also used the MLFMA algorithm to develop a hidden Markov model for processing SAR data, and the initial results appear promising. Finally, the project has considered the fundamental limitations of estimating decaying exponential parameters from EMI data in support of the modeling activity described above.

**TRANSITION:** The project intends to transition cooperative developments. These include organized cooperative agreements with ARL, NRL, and BBN.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** An Innovative Passive Barrier System Using Membrane-Delivered Hydrogen Gas for the Bioremediation of Chlorinated Aliphatic Compounds; CU-1124

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Michael Semmens; University of Minnesota – Minneapolis, MN

**FY 2000 FUNDS:** $455K

**DESCRIPTION:** The objective of this project is to examine the gas transfer behavior and performance of hollow fiber membrane curtains that are installed as passive barriers. The proposed research will assess the suitability and effectiveness of the membrane for delivering hydrogen ($H_2$) to accelerate the in situ remediation of chlorinated organic compounds like trichloroethene and perchloroethene.

The proposed research will investigate the behavior of the membranes in a systematic way to determine what factors control the overall remediation process. These tasks include: (1) gas dissolution behavior of membranes, (2) impact of gas composition changes and condensation, (3) impact of biofilm growth on gas transfer, (4) evaluation of solvent transformation, (5) mathematical model development, and (6) pilot reactor studies.

The risks involved in this process include the following. (1) The membranes may not transfer $H_2$ fast enough when the groundwater is moving so slowly. (2) The membranes may foul and their gas transfer performance may be lost. (3) Methanogens may exploit the high local $H_2$ partial pressure and grow preferentially. (4) Most of the $H_2$ will be used to form methane gas which could accumulate locally and impede effective bioremediation by halorespirers. (5) The accumulation of locally high concentrations of methane and $H_2$ are of concern, since both $H_2$ and methane are flammable gases. (6) The accumulation of excessive biomass locally could cause a loss of permeability and a poor flow distribution through the affected site. (7) The installation process may damage the membranes and render them ineffective.

**BENEFIT:** This proposal specifically responds to a SERDP statement of need with the overall goal of developing an innovative passive barrier remediation technology that will reduce the costs, risks, and time required for contaminated site cleanup. The proposed research will characterize the performance of a novel passive barrier that relies on the use of an innovative membrane technology for the controlled dissolution of $H_2$. The research will employ special woven hollow-fiber membranes for the passive dissolution of $H_2$ in order to accelerate the in situ bioremediation of groundwater contaminated with chlorinated compounds. The hollow fiber membrane curtain can act as both a gas supply and a biofilm support. These modules can be designed to provide a large surface area for gas transfer while presenting minimal hydraulic resistance to flow. Modules of woven fibers can be installed using trench technologies and placed to create a flow-through passive barrier that is oriented normally to the direction of groundwater flow. In this way the membrane curtain provides passive gasification of the groundwater flow without the need for pumped wells, gates, or other forms of flow modification.

Passive barrier remediation systems are an attractive treatment option for the transformation of contaminated groundwater. $H_2$ appears to be an effective electron donor for the biodegradation of halogenated aliphatics when it is sufficiently bioavailable. However, it is difficult to provide sufficient $H_2$ to organisms due to its low solubility. Gas permeable membranes, used as a passive treatment barrier, could be used to provide $H_2$ as an electron donor for in situ bioremediation. This method of $H_2$ delivery would be expected to provide controlled levels of bioavailable $H_2$ that should provide the same benefits as cathodically derived $H_2$, without the associated problems.

This SERDP funded research will prove the technical feasibility of using membranes for $H_2$ delivery to contaminated groundwaters. In addition, the project will yield the engineering data required to complete a cost analysis and transition the membrane-module remediation system technology into field scale application.

**ACCOMPLISHMENTS:** The column reactors have been designed and are currently being constructed. Membrane modules for use in the column reactors are designed and will be constructed once the column reactors are complete (to ensure correct sizing). A recirculating-gas loop has been designed and constructed to control the partial pressure of $H_2$ at a very low and constant level in the membranes. The loop allows for automatic addition of $H_2$, automatic recording of $H_2$ partial pressure, and manual control of $H_2$ partial pressure within the membranes. Control software (LabVIEW) is currently being programmed to allow automatic control of the $H_2$ partial pressure within the membranes. Initial model development has begun using a Computer Program for the Identification and Simulation of Aquatic Systems (AQUASIM), which is a versatile for modeling aquatic systems. A model has been built incorporating both halorespiration and methanogenesis and the subsequent competition for $H_2$. This model is applicable to the batch system. A model for the column system is currently under development. Kinetic coefficients are being used from the literature as suggested by the SERDP staff; however, preliminary model results suggest that more precise estimates of kinetic coefficients based on the Cape Canaveral microbial consortia are needed.

**TRANSITION:** The project intends to transition to the user community including, Porous Media, Minntech Corp. and Membran Corp. The project intends to select a site within DoD for field demonstration/validation.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Influence of Groundwater Constituents on Longevity of Iron-Based Permeable Barriers; CU-1125

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. A. Lynn Roberts; The Johns Hopkins University – Baltimore, MD

**FY 2000 FUNDS:** $260K

**DESCRIPTION:** This project investigates factors which may limit the longevity of iron-based permeable barriers used for in situ treatment of organic- or metal-contaminated groundwaters. This will be accomplished by examining the long-term performance of laboratory columns packed with a porous medium containing zero-valent metal solids through which simulated groundwater of differing compositions is passed, by examining the influence of eluent composition and time on the evolving composition of the solid surfaces, and by monitoring the electrochemical characterization of the surfaces after varying times of exposure. Particular emphasis is placed on developing new approaches for "real-time" monitoring of changes in system performance through a novel electrochemical probe that can be installed in situ in pilot - or full-scale applications.

The principal technical objectives are to evaluate the impact of groundwater composition on the long-term performance of zero-valent iron (Fe) barriers and to develop a prototypic electrochemical probe for monitoring reactivity changes at either the field or laboratory scale. This project intends to conduct an integrated research program to meet the following specific objectives:

- to understand the effects of groundwater chemistry on long-term barrier performance, including delineation of the impacts of chemical reactivity changes and alterations in transport properties;
- to develop an electrochemical probe that can be used to continuously assess the ongoing performance of a reactive barrier, either in laboratory columns or in situ in the field;
- to develop a fundamental understanding of the causes of alterations in reactivity through studying its relationship to the changing composition of the iron surface;
- to incorporate the results of these studies into a set of guidelines that can be used to predict the impact of the above factors on reactive barrier performance.

**BENEFIT:** The major output of this work will be basic research: first and foremost, an improved understanding of the impact of the aqueous chemistry on the longevity of iron, both from the perspective of "aging" and also from clogging. This project should provide a fundamental understanding of important issues dictating barrier longevity, allowing improved assessment of life cycle costs. The project team will use the results to design guidelines that outline reasonable "safety factors" concerning assumed permeable reactive barrier residence times as a function of design life of the barrier. Overall, the results of this work will allow better evaluation of the tradeoff between construction costs (e.g., barrier thickness) and system longevity. The understanding and tools developed through this effort will be directly relevant to users who apply permeable iron-barrier technology for treatment of chlorinated solvents or explosives at DoD/DOE sites. The electrochemical probe to be developed through this work has considerable promise for rapid implementation as a tool for monitoring reactivity changes in full-scale applications.

**ACCOMPLISHMENTS:** In FY99 this project progresses among several different areas. These areas are highlighted below.

***New Column Development:*** New plexiglas columns have been machined and are ready to be equipped with sampling ports. The size fractionation of the iron to be used in these columns is near completion. The column experimental setup was completed. This includes gas sparging of reservoir carboys, peristaltic pump for reservoir fluids, syringe pump for contaminants, mixing chambers for two pump flows, columns, effluent collection system and treatment by Granular Activated Carbon (GAC) prior to discharge.

***Conservative Tracer Experiments:*** Researchers are currently investigating the use of SF6 as a nonreactive but volatile tracer to help quantitate the volume of the gas phase in the columns. The routine tritiated water tracer tests to assess the average residence time of mobile water in the columns will be extended to provide information on changes of the transport parameters along the column length.

***Electrochemical Probes:*** A number of silver/silver chloride reference electrodes were assembled and subjected to various tests. Their overall performance indicates sufficiently low impedance and satisfactory long-term stability. The computer code developed allows the research team to monitor the open-circuit potential and electrochemical potential noise of up to eight electrodes. The Team is currently finalizing the design for the electrochemical probes.

***Surface Characterization:*** Characterization of the virgin iron particles by Auger Electron Spectroscopy indicates that significant amounts of carbon are located in "patches" on the particle surface. Iron and oxygen are strongly associated with one another on the surface, where not occluded by carbon "patches". A second result from this characterization of "virgin" particles is the finding that the deepest pores in the surface oxide coating extend several μm into the particle. The etch rate of the ion gun used was calibrated by sputtering clean a copper surface onto which an iron oxide of known thickness had been grown.

**TRANSITION:** The project intends to transition through the Environmental Security Technology Certification Program (ESTCP), Air Force Research Laboratory (AFRL), Air Force Center for Environmental Excellence (AFCEE), EnviroMetal Technologies, Inc., and the Remediation Technologies and Development Forum Permeable Barriers Working Group.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Development of Effective Aerobic Cometabolic Systems for the In-Situ Transformation of Problematic Chlorinated Solvent Mixtures; CU-1127

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Lewis Semprini; Oregon State University – Corvallis, OR

**FY 2000 FUNDS:** $462K

**DESCRIPTION:** The projects objective is to remediate trichloroethylene (TCE) and other chlorinated organic compounds in soil and groundwater. The goal of the proposed research is to demonstrate the potential of using propane and butane-utilizing microorganisms to transform problematic Chlorinated Aliphatic Hydrocarbons (CAH) mixtures. The demonstration will be aimed towards creating in situ bioreactive passive barriers in contaminated aquifers. Oregon State University research with microorganisms stimulated on propane or butane has demonstrated the potential for transforming a broad range of CAH mixtures that have been problematic with other cometabolic substrates. Microcosm studies conducted with subsurface solids and groundwater from contaminated Department of Defense (DoD) sites, however, have shown that propane and butane-utilizers are often absent in the subsurface, or have long lag periods before effective stimulation is achieved. Thus the implementation of effective in situ treatment systems at many sites will likely require bioaugmentation. The proposed work will demonstrate effective methods to create passive treatment barriers through both bioaugmentation and the use of a subsurface delivery system. Bioaugmentation will serve only to add effective propane or butane-utilizers to the treatment zone. Microbial growth and maintenance for effective cometabolic treatment will be achieved through propane or butane addition to the subsurface. In addition, the project will explore the use of mixed cometabolic substrates for the treatment of problematic CAH mixtures.

The technical approach for this project will consists of four components: (1) Laboratory studies to select the bioaugmentation approach and to develop kinetic information for single substrate (propane or butane) and mixed substrate addition (propane and phenol, for example) for the transformation of CAH mixtures. (2) Explore molecular probe methods for tracking the bioaugmentation and biostimulation in laboratory and field studies. (3) Field demonstrations to evaluate the bioaugmentation approach and to determine the effectiveness in treating problematic mixtures of 1,1,1-TCA, 1,1-DCE, and TCE using propane or butane as a single cometabolic substrate, and mixed cometabolic substrates, propane or butane with phenol or toluene, in the latter stages of the field tests. (4) Modeling evaluations of the laboratory studies and the field studies, including simulations to aid in the design of the field demonstration tests.

**BENEFIT:** The primary benefit from the outcome of this project will be a field documented in situ cometabolic process that transforms problematic mixtures of CAH's. This technology will be a new in-situ application of aerobic cometabolism for complex CAH mixtures. In addition, a bioaugmentation methodology for in-situ cometabolism will be developed to be possibly used as a remediation alternative for sites where natural attenuation or biostimulation will not work. This technology may be used a passive process that can be applied in deep aquifers or in a stratigraphy with multiple clay lenses. Other products from this research include developing an approach for establishing effective microbial communities for in-situ cometabolic treatment, modification to the Cometabolism Transport Model, assessment of community structure changes with bioaugmentation and cometabolic transformation, and specific probe method development for propane and butane bioaugmentation cultures.

**ACCOMPLISHMENTS:** Laboratory efforts have focused on: (1) demonstrating the ability to grow the butane and propane mixed cultures in a media formulation; (2) bioaugmenting the culture into soil/groundwater microcosms; and (3) evaluating substrate uptake and CAH transformation. Propane-utilizers were easily stimulated after not being fed propane for one year and very effectively transformed 1,1,1-TCA. Rapid transformation of 1,1,1-TCA has continued for over 20 days after propane was consumed.

After two months, butane-utilizers began uptaking the butane. Then the bioaugmentation enrichment was grown from the seed culture obtained from the soil/groundwater microcosms that showed the most effective butane-utilization and 1,1,1-TCA transformation abilities. Rapid rates of 1,1,1-TCA transformation correlated with rapid rates of butane consumption. 1,1,1-TCA transformation continued for several weeks after butane had been consumed. The seed culture was then inoculated into nutrient rich media and harvested and bioaugmented into a series of groundwater and soil microcosms and media controls. These studies are still in progress. Currently evaluating the ability of the bioaugmented culture to transform 1,1,1-TCA. The transformation ability is being compared with results obtained when the culture is grown in media and with groundwater microcosms that were directly seeded from the original groundwater microcosm. These data will help determine whether effective transformation was maintained upon growing the culture used for the bioaugmentation in media. Progress in the molecular probe studies include isolating pure cultures to be used in the development of the probes and evaluating different procedures for obtaining DNA from the cultures.

**TRANSITION:** The project intends to transition to the Environmental Security Technology Certification Program (ESTCP).

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Nonintrusive Characterization of Dense Nonaqueous Phase Liquids Using Short-Lived Radiotracers in Partioning Interwell Tracer Tests; CU-1128

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Phillip A. Gauglitz; Pacific Northwest National Laboratory – Richland, WA

**FY 2000 FUNDS:** $488K

**DESCRIPTION:** The objective of the proposed research is to develop partitioning interwell tracer testing using short-lived radioisotopic tracers as an effective characterization technique for Dense Nonaqueous Phase Liquids (DNAPL) in the subsurface. This technique can be viewed as the next evolution in partitioning tracer testing and offers significant benefits over currently available technologies. By injecting conservative and partitioning short-lived radioisotopic tracers into the subsurface and continuously measuring their presence in monitoring wells with moveable downhole detectors, the location and amount of DNAPL can be measured to a much greater extent than can now be achieved by any other method.

The technical approach for this project is to develop the radiochemical techniques for making tagged tracers together with assembling suitable detectors. After the field prototype has been tested, the tracers and sensors will be used in a field application to further develop the method. The field testing will be guided by detailed fluid flow modeling, as will the interpretation of the field results. The tasks for this project are: (1) Detector and Logging System Development, (2) Tracer Selection and Radiochemistry Techniques, (3) Laboratory Testing, (4) Pre-Test Modeling and Field Test Planning, (5) Field Testing, (6) Inverse Modeling (Data Analysis), and (7) Development of a Guidance Document.

**BENEFIT:** The proposed research will develop an innovative, nonintrusive radiotracer methodology for reliably detecting, quantifying, and determining the horizontal and vertical extent of non-aqueous phase liquids (NAPLs) in the subsurface environment. The desired information will be available in an easily interpretable format and will provide the ability to detect and delineate subsurface NAPLs to an extent beyond any existing technology. This additional information will substantially improve risk assessment, remedial system design, optimization of remedial operations, and verification for site closure.

The proposed research will lead to a cost-effective technique for more precisely locating DNAPL sources, estimating the mass, and monitoring the transport and/or reduction of the mass over time, which are critical aspects of cost-effective cleanup. It is anticipated that the costs to implement the developed technology will be comparable to those of conventional partitioning interwell tracer tests, with significantly more characterization information achieved.

**ACCOMPLISHMENTS:** Work to date includes the preliminary identification of tracers and radioisotopes and concepts for the radiotagging of the tracers. Also, concepts have been developed for specific testing to determine depth of field and detector response.

**TRANSITION:** The project intends to transition the complete package for deployment in saturated and/or unsaturated DNAPL zones within DoD sites. The technology will be deployable by site personnel or service companies. Interest has been expressed by Current Environmental Solutions, Inc. and others.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Biological Assessment for Characterizing Contaminant Risk at the Genetic-, Individual-, and Population-Level; CU-1129

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Todd Stephen Bridges; U.S. Army Corps of Engineers Engineer Research and Development Center, Environmental Laboratory – Vicksburg, MS

**FY 2000 FUNDS:** $518K

**DESCRIPTION:** The objective of this project is to develop a suite of technically defensible assays that can be effectively used in regulatory programs to quantify the ecological risk of contaminated sediments at the molecular-, individual-, and population-level. Researchers will quantify the biological/ecological meaning of genetic responses, collected using genosensors, by way of comparison to whole-organism assessments of toxicity and modeled population-level impacts. Dose-response information will be simultaneously generated using genosensors and whole-organism bioassays for such military-relevant compounds as explosives trinitrotoluene (TNT), cyclotrimethylenetrinitramine (RDX), cyclotetramethylenetetranitramine (HMX), other organics such as polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbon (PAH), and metals such as lead (Pb).

During the first phase of this project, (1) sediments will be spiked with single military-relevant compounds (i.e., explosives and other organics) and mixtures at a range of concentrations, (2) sediment-dwelling organisms will be exposed to these contaminated sediments, (3) the sediments and organisms will be screened for the presence of genetic markers using developed genosensors, and (4) whole-organism effects on survival, growth and reproductive endpoints will be measured. Four sediment-dwelling organisms will be used in this project that are currently being used by the Environmental Protection Agency (EPA) and the Corps to develop chronic, sublethal sediment bioassays for national regulatory programs. Two of the species occur in marine habitats (Neanthes arenaceodentata and Leptocheirus plumulosus) and two of the species are found in freshwater habitats (Hyalella azteca and Chironomus tentans). Impacts at the population-level will be projected using population models developed for bioassay organisms during the course of this study. By simultaneously measuring biological responses at three distinct levels of biological organization (i.e., genes, whole organisms, populations) the team of researchers will have the ability to effectively test the reliability of estimating potential risk at higher levels of organization (e.g., ecosystems) using information that can be quickly and inexpensively collected at lower levels of organization (i.e., the level of genes).

During the second phase of study, the bioassay suite will be tested using naturally contaminated sediment containing even more complex mixtures of military-relevant and conventional contaminants. The comparisons made among the endpoints at each level of organization using field collected sediments ranging in degree of contamination will allow researchers to test how robust their predictions will be under a regulatory use scenario.

**BENEFIT:** Currently there is a lack of defensible methods to measure and assess ecosystem responses to insults by Department of Defense (DoD) relevant contaminants. Large uncertainties surround current cleanup goals for military-unique contaminants (MUC) and estimates of environmental risk resulting from exposure to MUCs. The large assumptions and extrapolations required by current approaches necessitates the use of large safety/uncertainty factors which lead to very conservative cleanup goals that are very expensive to obtain with current cleanup technologies. This project will provide tangible benefits to DoD cleanup efforts by reducing the driving uncertainties in the estimation of risk in MUC contaminated sediments, namely, (1) contaminant bioavailability, (2) the toxicity of MUCs, (3) the toxicity of complex MUC mixtures, and (4) extrapolating to higher order effects (e.g., population-level impacts). The methods and data generated during this project will improve DoD's capability to defensibly define risk to aquatic organisms exposed to MUCs and to set reasonable cleanup levels that are based on the potential for toxicity

at multiple levels of biological organization. Given the number of contaminated DoD/DOE sites (17,000), the potential for remedial cost avoidance is considerable.

**ACCOMPLISHMENTS:** The toxicological effects of three explosives, RDX, HMX, and TNT, as well as the degradation products of TNT, DANT and TNB, were assessed utilizing two freshwater and two marine invertebrates. Survival of Hyalella azteca, Chironomus tentans, Leptocheirus plumulosus, and Neanthes arenaceodentata was assessed in water only exposures for 96 hours to all five of the model compounds. LC50 values were calculated and utilized to determine appropriate concentrations for spiked sediment exposures and comparison of marine and freshwater organism response sensitivity. Amphipods (L. plumulosus and H. azteca) were more sensitive to the model toxicants than were non-amphipod experimental organisms. Organisms were most sensitive to TNT and TNB and least sensitive to RDX and HMX. In addition, experiments were conducted to determine survival and growth of C. tentans following a 10-day exposure to all five model toxicants. TNT was the most potent toxicant in reducing the survival of midges in the sediment exposures. No significant decreases in mortality were observed following exposure to RDX and HMX. Chemical analysis of sediment samples collected from marine experiments revealed that TNB and DANT degraded rapidly whereas RDX and HMX persisted throughout the exposure period. A degenerate PCR strategy using COnsensus-DEgenerate Hybrid Oligonucleotide Primers (CODEHOP) primers was used to isolate gene fragments belonging to six different gene families from Leptocheirus and Neanthes for use as gene probes in the ecotoxicity genosensor. Ninety four gene fragments were recovered from Neanthes and 126 from Leptocheirus and sequenced to determine their identity. Team members were successful in isolating genes similar to DNA topoisomerase 1 (Leptocheirus), superoxide dismutase (Leptocheirus), cyclin (Neanthes), actin (Neanthes, Leptocheirus) and the p450 super family (Neanthes, Leptocheirus) but not glutathione-S-transferase. Gene fragments were also isolated for reverse transcriptase (Neanthes, Leptocheirus) and kinases (Neanthes, Leptocheirus). Sixty one Leptocheirus clones and 72 Neanthes clones remain unidentified. Cloned PCR fragments are currently being tested in a DNA array format to determine the utility of the clones in monitoring toxicity. Preliminary results indicate that the expression of several cloned genes is reduced upon exposure of Neanthes to HMX while expression of a few increased, demonstrating that the gene isolation strategy has been successful in isolating target genes for microarray analysis.

**TRANSITION:** The project intends to transition to the Environmental Security Technology Certification Program (ESTCP).

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Evaluation of Performance and Longevity at DoD Permeable Reactive Barrier Sites; CU-1140

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Chuck Reeter; Naval Facilities Engineering Services Center – Port Hueneme, CA

**FY 2000 FUNDS:** $250K

**DESCRIPTION:** Site-specific conditions should be the ultimate factor in designing a permeable reactive barrier (PRB) remediation solution and the site performance and compliance monitoring plan should evaluate its operating effectiveness. Because the main goal of installation cleanup is to ensure that contamination is remediated and ultimately prevented from progressing further downgradient of the site, monitoring is needed to evaluate the capture and treatment efficiency of the PRB configuration. Since all current PRBs have somewhat different design configurations, it will be important to evaluate certain selected sites using a consistent approach. The purpose of this Department of Defense (DoD) (SERDP/ESTCP) project and its two companion projects with the Department of Energy (DOE) and the Environmental Protection Agency (EPA) is to achieve combined Federal agency coordination in addressing these various performance and longevity issues at specific Permeable Reactive Barrier (PRB) projects. The DoD, EPA, and DOE projects are being executed simultaneously for a leveraged effort that will achieve maximum coordination to minimize duplication and to ensure that the most cost-effective measures will be implemented. Project coordination will ensure that data collected from each site are comparable, while allowing each agency to focus on its unique needs.

This SERDP/ESTCP project is intended to specifically focus on the DoD sites, only. The EPA and DOE will provide separate funding for their selected sites. Similar to the DOE and EPA projects, the DoD SERDP/ESTCP project approach will be conducted using the following tasks: (1) Field Monitoring Survey and Site Selection, (2) Performance Sampling at Selected PRB Sites, and (3) Performance Data Evaluation.

**BENEFIT:** It is estimated that potentially 500-1,000 DoD sites could use the PRB technology. Using actual site specific data from cost analyses performed at one Navy location, the results can typically represent most DoD sites. At Naval Air Station (NAS) Moffett Field, it would cost about $9 Million (M) to remediate the site by using a full-scale PRB over a 50-year period. Conversely, it would cost about $33M over a 50-year period using the groundwater pump-and-treat method. Specifically for Moffett, over the long term, the cost savings ratio of using the PRB technology over pump-and-treat can be as much as 4 times. Overall, it is estimated that the Moffett site can save about $24M in contaminant plume remediation costs. It is reasonable to conclude that over the long term, billions of dollars could be saved at hundreds of chlorinated compound contaminated sites where the PRB technology can potentially be applied.

**ACCOMPLISHMENTS:** Over the last year the project has completed the field monitoring survey and site selection. The project has established regular conference calls with other DoD tri-service partners and Remediation Technology Development Forum (RTDF) collaborators. The project also completed a Demo Site Selection Report that includes results from surveys from DoD, DOE, and EPA sites.

**TRANSITION:** The project intends to transition through the Environmental Security Technology Certification Program (ESTCP).

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Environmental Toxicology Earmark; CU-1141

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Daniel Erwin; Texas Tech University – Brooks AFB, TX

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** There were two objectives of this earmark project:

- Develop a scientifically-based environmental standard for type 8 jet fuel (JP-8) exposure to the general population at Air Force bases intented to characterize potential acute health effects associated with JP-8 and recommend actions to ameliorate disease/injury in exposed personnel. The project worked to develop a scientifically based environmental standard of jet propulsion JP-8 exposure for the general population at US Air Force (USAF) bases. In addition this project worked toward: (1) assessing the environmental impact of jet fuel use, thereby understanding the parameters required to achieve a safe community environment; and (2) characterizing the potential acute health effects associated with JP-8 and recommend actions to ameliorate disease/injury in personnel exposed to jet fuel.

- Perform ecological risk assessment/modeling of contaminant mixtures that would: (1) develop/validate aquatic models for assessing effects of water-borne contaminants on aquatic fauna development and reproduction; (2) develop and validate terrestrial models for assessing effects of contaminants on terrestrial species development and reproduction; and (3) integrate data using models and Geographical Information System (GIS) to predict the effects of contaminants on both individuals and populations. This task entailed four areas:

  - ***Aquatic Toxicology:*** To develop and validate aquatic models for assessing the effects of water-borne contaminants on the development and reproduction of aquatic fauna in and around USAF bases. Determine effects of contaminant mixtures on development and reproduction of aquatic fauna. Determine the effects of larval exposure to contaminant mixtures on adult reproductive parameters. Development of scientific data relative to exposure of adult versus juvenile animals in the aquatic fauna. Evaluation of non-lethal bio-markers of amphibian and fish that can be used in extrapolation and risk assessment following exposure to mixtures. Provide data on aquatic exposure for further extrapolation and risk assessment of environmental chemical mixtures.

  - ***Terrestrial Toxicology:*** Determine the effects of mixtures containing Ammonium Perchlorate (AP), Cadmium (Cd) and Arsenic (As) on development, growth, and reproduction at postnatal day 21 and 70, following in-utero and lactational exposure of deer mice (Peromyscus maniculatus). Evaluate steroid-metabolizing enzyme profiles in liver or gonads of mice following exposure to these mixtures. Investigate wild rodents from terrestrial field experiments. Development of scientific data relative to exposure of adult versus juvenile following in utero and lactational exposure to mixtures (AP, Cd and As) using a wildlife sentinel rodent model (peromyscus maniculatus). Evaluation of non-lethal biomarkers that can be used in extrapolation and risk assessment following exposure to mixtures. Provide data on terrestrial exposure for further extrapolation and risk assessment of environmental chemical Analytical Evaluations in Support of Toxicological Evaluations. Analytically evaluate AP in environmental samples using ion chromatography. Determine AP partitioning behavior between n-octanol and water. Determine the fate of AP in aquatic systems in a way similar to hydrolysis studies used in the registration of agrochemicals. Determine leaching behavior of AP in soil using characterized soil columns.

- *Analytical Evaluations in Support of Toxicological Evaluations:* Basic environmental chemistry information on AP.

- *Environmental Modeling:* Two integrated models were developed based upon the laboratory and field experiments: (1) An Aquatic Model to predict effects of AP on frog and fish populations and (2) A Terrestrial Model to predict effects of AP on small mammal populations.

**BENEFIT:** The research described addresses mixtures in a risk-based approach providing cutting edge science to the Department of Defense to address regulatory mandates they are facing related to site remediation and base closures. This research was accomplished through the integration of classical toxicology, chemistry, epidemiology, and modeling.

**ACCOMPLISHMENTS:** In FY99 the project made progress in both the JP-8 health risk assessment and in the ecological risk assessment areas.

***Jet Fuel Health Risk Assessment and Epidemiology Study:*** An initial epidemiology meeting was held in January to determine the Interagency and Interdisciplinary approach to support the over all assessment of risk of JP-8 to exposed populations, develop survey parameters, and to define study design. This meeting was able to provide parameters to strengthen and support the JP-8 risk assessment, including, but not limited to, determination of subject eligibility, sample size, participating subject health history, exposure history, health outcome measures, control selection and site selection criteria.

***Ecological Risk Assessment/Modeling – Mixtures:*** In the areas of aquatic toxicology and terrestrial toxicology the project team was able to develop research protocols unique to each species. These protocols approved by a quality assurance unit. The animal use protocols were then submitted and approved by the Texas Tech University (TTU) animal use committee and forwarded to Brooks AFB. Currently the project is developing and adapting Ribonucleic Acid (RNA) isolation techniques for mice and Xenopus. The field component has completed site selection coordination with the Air Force (AF) and Interagency Perchlorate Steering Committee (IPSC). The environmental modeling aspect of this project currently developing models for plant growth and plant uptake.

**TRANSITION:** Identification and validation of bio-markers associated with exposure to JP-8 fuel which will provide the Air Force with immediate tools for risk assessment. Development and validation of bio-markers following exposure of amphibians, fish and rodents to chemical mixtures which can be used by the Air Force in future risk assessment of chemical mixtures.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** In-Situ Bioreduction and Removal of Ammonium Perchlorate; CU-1162

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. John Coates; Southern Illinois University – Carbondale, IL

**FY 2000 FUNDS:** $122K

**DESCRIPTION:** This project will provide a better understanding of the microbiology involved in microbial perchlorate reduction and removal. The factors controlling the applicability of these microorganisms to the in-situ treatment of ammonium perchlorate contamination of natural water supplies will be determined. In addition, this work will assist in the development of protocols and molecular tools required for the modeling and application of in-situ bioremediation strategies to treat perchlorate contamination in the environment.

The objectives of this project will be addressed under the following hypotheses.

***Hypotheses 1.*** Perchlorate-reducing bacteria are ubiquitous and are indigenous in perchlorate contaminated environments. The perchlorate-reducing population in the samples will initially be enumerated by most probable number counts (MPN) with acetate as the electron donor. In addition, the predominant indigenous perchlorate-reducing bacteria (ClRB) in the samples will be determined by Polymerase Chain Reaction (PCR) amplification with specific primers followed by Denaturing Gradient Gel Electrophoresis (DGGE) analysis and sequencing.

***Hypotheses 2.*** All perchlorate-reducing bacteria contain a conserved chlorite dismutase enzyme. In order to evaluate this hypothesis the researchers will use the purified chlorite dismutase enzyme from the ClRB, Dechlorimonas agitatus strain CKB, to determine the N-terminal sequence, and develop a specific molecular probe to the gene that codes for this enzyme. Following sequence analysis of the gene, universal probes for ClRB will be constructed.

***Hypotheses 3.*** Indigenous microbial perchlorate reduction can be easily stimulated in contaminated environments. As all ClRB isolated to date are alternatively able to utilize nitrate as an electron acceptor, the addition of nitrate to the environment should result in an increase in the perchlorate-reducing microbial population. Sediment samples will be enriched under anaerobic conditions by nitrate and acetate addition and tested for stimulation of perchlorate reduction.

***Hypotheses 4.*** The stimulated perchlorate reducing population can remove perchlorate concentrations to levels significantly lower than 18 ug/L. Several of the phylogenetically diverse ClRB isolates in the projects laboratory cultures will be selected and grown individually in continuous culture in a chemostat. Once steady state is achieved, temperature, pH, ion concentration, dissolved oxygen concentration, and perchlorate concentration will be varied individually. Final perchlorate concentrations achieved by each organism under all conditions will be determined and compared.

***Hypotheses 5.*** The rate of microbial perchlorate reduction will be affected by the environmental conditions. To determine the controlling factors of perchlorate reduction, samples enriched with acetate and nitrate will be used. Specific perchlorate-reducing activity will be determined in subsamples under a range of redox, pH, and temperature values, as well as ionic strength, and perchlorate concentrations to determine optimum conditions for perchlorate reduction. In addition, the effect of the presence of alternative electron acceptors will also be determined.

***Hypotheses 6.*** The stimulated perchlorate-reducing population will also enhance biodegradation of co-contaminating organics. Degradation of 14-C-labeled hydrocarbons by perchlorate-reducing enriched samples will be determined by monitoring 14-CO2 production over time.

**BENEFIT:** Results from these studies will result in a better understanding of the microbiology involved in perchlorate reduction and the factors controlling the activity of these organisms. These studies will also allow the development of a molecular probe which will be specific for all perchlorate-reducing bacteria. Such a probe can be used for predictive determinations of the success of a biological in-situ treatment process and also as a monitoring tool for intrinsic or enhanced bioremediative efforts. Finally this study will identify the potential of a stimulated perchlorate-reducing population.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** All results produced during the course of this project will be published in peer reviewed journals and be accessible to the public. Project researchers are in the process of developing a World Wide Web page devoted to ongoing research in the area of microbial perchlorate reduction in their respective laboratories. The results, tools, and techniques produced as part of the above proposed research will be documented at this site. In addition, current ongoing research on the microbiology of perchlorate reduction has resulted in 4 patent applications which have attracted the interest of several biotechnological/ bioremediation companies.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** In Situ Bioremediation of Perchlorate; CU-1163

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Paul Hatzinger; Envirogen, Inc. – Lawrenceville, NJ

**FY 2000 FUNDS:** $276K

**DESCRIPTION:** The discharge of contaminated effluents during the manufacture and replacement of propellants in military missiles and rockets has resulted in substantial perchlorate contamination in groundwater in several states, including California, Utah, Texas, and Nevada. The objective of this SERDP project is to develop a biological treatment technology for the in situ remediation of perchlorate in groundwater. The experiments proposed in this effort are designed to provide a fundamental understanding of the factors promoting perchlorate degradation in subsurface environments as well as the conditions that inhibit this process. Laboratory microcosms and flow-through model aquifers with sediments and groundwater collected from perchlorate impacted sites will be used during the project.

This project intends to conduct research over several areas. These areas are highlighted below.

***Task 1. Collect Aquifer Solids and Groundwater from Field Sites:*** Aquifer samples will be collected from known or potential perchlorate contaminated sites, including commercial remediation sites, and military sites. Ideally, aquifer solids and groundwater will be obtained from at least three field sites with different geochemical characteristics. These samples will be used in microcosm studies to represent the range of different environments that have experienced perchlorate contamination.

***Task 2. Obtain Microbial Consortia and Individual Bacterial Isolates Capable of Perchlorate Degradation:*** The objective of this task is to isolate individual perchlorate degrading bacteria or a mixed bacterial culture from pilot and full-scale Fluidized Bed Reactor (FBR) systems that are currently reducing perchlorate in water to non-detectable levels. The resulting consortia and/or individual strains will then be used in subsequent microcosm and flow-through column experiments to evaluate the potential for bioaugmentation as an in situ remediation strategy for perchlorate.

***Task 3. Identify Conditions Required for In Situ Biostimulation of Perchlorate Degradation:*** The objective of this task is to develop an understanding of the factors promoting perchlorate degradation in subsurface environments as well as the conditions that inhibit the process.

***Task 4. Construct and Operate Pilot-Scale Model Aquifers:*** The most effective treatments (biostimulation and/or bioaugmentation) for perchlorate degradation in the microcosm studies will be further tested using pilot-scale flow through model aquifers.

***Task 5. Biodegradation Modeling:*** Groundwater flow and reactive transport modeling will be conducted to verify degradation rates derived from laboratory studies and to aid design of field-scale applications. The model aquifers will be used to determine substrate (electron donor) loading rates, perchlorate reduction kinetics by natural and inoculated strains, and inhibitory concentrations of groundwater constituents such as nitrate and oxygen.

**BENEFIT:** The research outlined in this proposal will provide extensive information on (1) the potential for successful perchlorate remediation at subsurface sites by addition of electron donors (i.e., biostimulation); (2) the most effective electron donors to use in biostimulation efforts, and the expected concentrations and remediation kinetics achievable with these donors; (3) the possibility for successful bioaugmentation (i.e., injection of bacterial isolates) for subsurface perchlorate remediation; and (4) the probable influence of alternate electron acceptors and environmental variables on perchlorate reduction during biostimulation

and/or bioaugmentation efforts. These data will provide the fundamental knowledge required for the design and implementation of pilot-scale and full-scale remediation efforts at perchlorate contaminated sites.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** The long-term goal of this project is to develop and demonstrate a technology that can be easily transitioned to field deployment. The final report will include a section that identifies the most viable methods for field implementation based on the research findings and modeling results. At the conclusion of the SERDP studies, ESTCP or other funding will be sought to demonstrate the most promising remediation strategy in a field study, an application protocol will be prepared, and Envirogen will then commercialize and license the technology.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** In Situ Bioremediation of Perchlorate-Impacted Groundwater; CU-1164

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Evan Cox; GeoSyntec Consultants Inc. – Huntington Beach, CA

**FY 2000 FUNDS:** $115K

**DESCRIPTION:** Groundwater contamination related to the production, handling and use of rocket propellants such as ammonium perchlorate has been identified as a widespread problem at Department of Defense (DoD), Department of Energy (DOE) and defense contractor facilities. Few cost-effective technologies exist for the treatment of perchlorate-contaminated groundwater. Of the technologies being evaluated, in situ bioremediation is among the most promising because it has the potential to destroy perchlorate in place rather than transferring perchlorate to another waste stream (e.g., impacted resin or brine) requiring treatment or disposal.

This research program consists of: (1) laboratory microcosm studies to evaluate the ubiquity of perchlorate-degrading bacteria in groundwater at a variety of impacted DoD, DOE and defense contractor facilities, and to assess the applicability of in situ bioremediation as a remedial technology in a variety of geochemical environments; followed by (2) small-scale field pilot testing at one of the test sites to demonstrate that perchlorate can be biodegraded under field conditions, and to generate initial design and cost data for potential technology scale-up and validation. The product of this research will be the development of a robust, reliable and cost-effective treatment technology for perchlorate-impacted groundwater at DoD, DOE and defense contractor facilities.

**BENEFIT:** The presence of perchlorate in drinking water supplies is a national concern that requires the timely development of robust, reliable and cost-effective treatment technologies for large volumes of groundwater. Cleanup costs for perchlorate-impacted groundwater are expected to be in the $100Ms in California alone, the cost of which may jeopardize major DoD and propulsion contractor production programs. The support of cooperative development partners such as, Aerojet General Corporation and the U.S. Navy, for the proposed research program highlights the need for development of cost-effective and environmentally-acceptable perchlorate treatment technologies.

A significant number of other federal and defense contractor facilities may benefit from the development of cost-effective in situ remediation technologies for perchlorate-impacted groundwater. For example, the Environmental Protection Agency (EPA) has identified at least 14 facilities in California, including 7 Superfund sites, where perchlorate is present in groundwater, and where groundwater remediation is likely to be required once final groundwater standards are established. The majority of these sites are rocket manufacturers and testing facilities associated with DoD and National Aeronautics & Space Administration (NASA).

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** Through the proposed research program, the project team expects to develop a remediation technology ready for large-scale field demonstration (via ESTCP or similar program), validation and implementation. The early tasks of the project will contribute key knowledge improving the understanding of the ubiquity of perchlorate-degrading bacteria, and the potential applicability of in situ bioremediation for perchlorate-impacted sites. The small field pilot test will, within a relatively short timeframe, provide design and cost data so that the technology can be scaled-up, validated, and transitioned within DoD, DOE and industry for full-scale use.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Proposal to Develop Extraction Tests for Determining the Bioavailability of Metals in Soil; CU-1165

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Michael Ruby; Exponent Environmental Group – Boulder, CO

**FY 2000 FUNDS:** $355K

**DESCRIPTION:** The primary objective of the proposed project is to develop a suite of simple and easy-to-use extraction tests to predict human and ecological exposures to metals in soil. Such tests will provide inexpensive and rapid tools for establishing the bioavailability of metals in soils at hazardous waste sites. Soils used in the project will be characterized for metal species and soil parameters to provide a mechanistic basis for any differences in metals bioavailability among the samples. Therefore, results from the project will also provide an understanding of how various species of a metal may differ in bioavailability, and also how various soil properties may affect metals bioavailability and the stability of the measured bioavailability estimates.

The proposed project will be framed around specific metals (arsenic, cadmium, copper, lead, nickel, and zinc) that are cost drivers for remediation of soils at Department of Defense (DoD) sites, and will focus on the most important receptors and exposure pathways for these metals. Historically, oral exposures to humans and terrestrial receptors have dominated risk assessments. Recently, dermal exposures have become more important in human health risk assessments as the U.S. Environmental Protection Agency (EPA) adopts default dermal absorption values for some metals. As described below, an extraction technique developed by Exponent has already been demonstrated to predict human oral exposure to lead, arsenic, and other metals in soils. A research consortium founded by Exponent is currently completing validation of this method for lead, and working on validation of the method for arsenic. This project will extend application of this technique to other metals of concern (cadmium, copper, nickel, and zinc). The results of this extraction technique should also be applicable to assessing exposures of terrestrial mammals in ecological risk assessments. The project will include an evaluation of method parameters that might be modified to better predict relative bioavailability of metals in soil in different kinds of mammals (e.g., rodents vs. ruminants). A second aspect of the project will focus on assessing dermal absorption of arsenic and cadmium from soil. No studies have been conducted of dermal absorption of these metals from weathered soils. Initial studies will include animal studies and in vitro studies using human cadaver skin. After testing dermal absorption of these metals from weathered soils, development of a simple extraction test for dermal absorption will begin. For each soil tested, pore-water measurements of free metal ions will also be conducted to predict metal absorption in soil invertebrates. It is anticipated that this research will lay the groundwork for a suite of simple extraction tests that will enable the assessment of relative bioavailability of metals in soil to humans and a range of ecological receptors.

**BENEFIT:** Metals occur in soil as a complex mixture of solid-phase chemical compounds of varying particle size and morphology. These compounds include discrete mineral phases, coprecipitated and sorbed species associated with soil minerals or organic matter, and dissolved species that may be complexed by a variety of organic and inorganic ligands. The occurrence and relative distribution of an element among these various phases, and the physical relation between the phases and the soil, control an element's solubility, and hence, its bioavailability. A number of physical methods have been developed for evaluating metals species in soil, such as sequential extractions, x-ray diffraction, and electron microbeam techniques (e.g., scanning electron microscopy and electron microprobe), and each has its own advantages and limitations. However, given the complexity of metal mixtures in soil, it has proven quite difficult to extrapolate from information on metal speciation to defensible estimates of metals bioavailability (except for very simple systems composed of only a few pure mineral phases). As a result, the most promising simple tests for quantifying the bioavailability of metals from soil are extraction tests to measure the fraction of a metal that is soluble

and available for absorption. This same conclusion has been reached by individuals studying the bioavailability of other complex mixtures in soil, including polycyclic aromatic hydrocarbons (PAH). Evaluation of metal speciation in soils by electron microprobe analysis, as well as complete characterization of soil parameters, will be used to provide mechanistic explanations for the results of the extraction tests. Once developed, these simple tests will be useful for assessing metals bioavailability during site assessment, evaluating any changes to bioavailability after remediation or restoration, and studying the long- term stability of metal species in amended soils.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** The proposed research is designed to yield a suite of simple extraction tests that are inexpensive to perform, produce reliable results, and are predictive of metals bioavailability from soil to human and ecological receptors. These tools will then be available to DoD personnel for site- specific evaluation of metals bioavailability from soil at field sites, and will result in more accurate exposure and risk estimates that are still protective of human health and the environment.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Quantifying the Bioavailability of Toxic Metals in Soils; CU-1166

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Phil Jardine; Oak Ridge National Laboratory – Oak Ridge, TN

**FY 2000 FUNDS:** $287K

**DESCRIPTION:** The objective of this SERDP project is to investigate the relative bioavailability of the toxic metals Lead (Pb), Zinc (Zn), Copper (Cu), Cadmium (Cd), Arsenic (As), and Nickel (Ni) in soils, primarily in relation to the human health risk posed by soil ingestion which often controls the degree of cleanup required at metal-contaminated sites. Specific objectives of this investigation are to: (1) Measure changes in relative bioavailability over time in a wide range of soil types which may be encountered at DoD sites within the U.S.; (2) Develop a predictive capability to quantify toxic metal bioavailability on the basis of soil properties; and (3) Investigate the fundamental relationship between molecular-level speciation and bioavailability to enhance the understanding and predictive capability of the fate of toxic metals in soil. Following successful completion of the research project, these results will provide site managers and risk assessors with tools to make better initial estimates of site risk which can be used to prioritize site cleanups and to justify more definitive site-specific bioavailability studies such as detailed soil speciation investigations and in vivo studies.

One of the biggest challenges in investigating metal bioavailability is in selecting a measure of bioavailability. Since the bioavailability of a contaminant is often receptor dependent (e.g., the bioavailability of a metal in soil may be different to an earthworm than to a plant), fundamental (as opposed to site-specific) research requires general indicators of bioavailability. In this research, soil-metal bioavailability will be measured with two in vitro protocols: a physiologically-based extraction test (with an important flow-through modification) to estimate the bioavailability of soil-bound metals in the human gastrointestinal tract and extraction with diethylenetriaminepentaacetic acid (DTPA), a general indicator of ecological bioavailability. The bioavailability of Pb, Zn, Cu, Cd, As, and Ni will be measured as a function of time in metal-spiked soils with a wide range of soil properties. Metal-spiked soils will be used because the initial metal concentration and speciation can be controlled and changes in bioavailability and molecular-level speciation from the initial soluble metal can be followed with time. In addition, beginning with soluble metals will provide insight into the ability of soils themselves to limit metal bioavailability, without regard to any unique site-specific speciation, allowing development of a multivariable linear regression model to predict soil-metal bioavailability on the basis of soil properties. This research will also feature the use of a powerful technique, synchrotron-generated X-ray absorption spectroscopy (XAS), to monitor molecular-level speciation in unaltered soil samples. The research is an innovative response to the statement of need in that it: (1) will develop an a priori means to provide initial estimates of metal bioavailability without regard to site-specific bulk-phase speciation, which is difficult to measure and apply, and which is subject to change over time; (2) will measure the bioavailability of metals in soils relative to soluble metal species which eliminates systematic errors in bioavailability measurements; (3) proposes a dynamic flow-through methodology for measuring bioavailability which more closely replicates physiological conditions; and (4) uses synchrotron-generated XAS to monitor unaltered molecular-level speciation to provide a better fundamental understanding of the relationship between bioavailability and speciation. These results will contribute to DoD's goal of mission readiness by avoiding unnecessary diversion of DoD funds for unwarranted site cleanup.

**BENEFIT:** These results will provide site managers and risk assessors with tools to make better initial estimates of site risk and environmentally acceptable endpoints (EAE) than using the 100% relative bioavailability default value. Although site-specific data will always need to be considered in making final cleanup decisions, these results can be used to prioritize sites and to justify more definitive site-specific bioavailability studies such as detailed soil speciation investigations and in vivo studies. These results will

contribute to DoD's goal of mission readiness by avoiding unnecessary diversion of DoD funds for unwarranted site cleanup.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** The results of this research will be transitioned to DoD cleanup activities through both broad-based information transfer and site-specific technology transfer. One of the objectives of this research is to produce a validated, peer-reviewed model to estimate soil metal bioavailability in a wide range of soils based on soil properties. These results will made available to the public through the world-wide web, presentation at scientific meetings, and ultimately publication in refereed archival journals. These results will be extremely beneficial to a risk assessors and site managers as there are currently no methods for estimating bioavailability other than intensive site-specific investigations. The results of this research will also be transferred to specific site cleanup activities through model validation using contaminated soils from McClellan AFB.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Aerobic and Anaerobic Transformation of cis-DCE and VC: Steps for Reliable Remediation; CU-1167

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. James Tiedje; Michigan State University – East Lansing, MI

**FY 2000 FUNDS:** $276K

**DESCRIPTION:** Considerable research has focused on the anaerobic transformation of Perchloroethylene (PCE) and Trichloroethylene (TCE), which are among the most common chlorinated solvents found in groundwater. However, relatively little is known about the types of microorganisms and specific environmental conditions associated with the dechlorination of cis-1,2-dichloroethene (cis-DCE) and vinyl chloride (VC). Recent research identified four different microbial processes that are involved in the fate of these compounds in groundwater. These processes include anaerobic chlororespiration, anaerobic energy-yielding oxidation, aerobic co-oxidation, and aerobic energy-yielding oxidation. The microbiology of each process will be characterized, and the team of researchers will evaluate each process for its potential applicability for groundwater remediation. Specifically researchers will compare (1) the different dechlorination/degradation processes for their requirements and their rates, (2) subsequently focus on the most viable process(es) or combinations thereof, (3) develop the basic physiological understanding and molecular methods for detection of the most active organisms, and (4) combine the microbial information with site geochemical and activity information to produce criteria for site specific recommendations.

With the current state of knowledge it is not possible to predict which microbial process will be most successful for a particular site. Hence, the first goal is to identify the important bacterial processes that lead to complete detoxification of cis-DCE and VC at high rates. After identifying the relevant processes researchers will focus on the identification, isolation, and physiological and ecological characterization of the important microbial populations involved in these processes. The Team will then evaluate how these biological processes can be stimulated, and also what the limitations of the individual processes are. With the knowledge gained from this work researchers will be able to predict how to stimulate the most promising process at a particular site, or whether natural conditions will sustain a sufficient rate.

The following objectives will be addressed during the 3 year period of the proposed research: (1) Identify the processes that result in the rapid degradation of cis-DCE and VC under aerobic and anaerobic conditions. (2) Identify the important groups of organisms involved in cis-DCE and VC degradation/ dechlorination. (3) Determine mechanisms of enhancing the cis-DCE/VC degradation rates of the individual processes. (4) Isolate cis-DCE/VC degrading/dechlorinating organisms in pure culture. (5) Characterize the physiology and phylogeny of the most important cis-DCE/VC degrading/dechlorinating organisms. (6) Investigate how site-specific characteristics determine which of the above identified processes is the most promising bioremediation strategy. (7) Develop a protocol to evaluate site-specific characteristics in order to facilitate decisions on which process is most promising for a particular site.

**BENEFIT:** Laboratory research in this project will provide insight into which factors may control anaerobic and aerobic transformation of cis-DCE and VC. The results of microcosm studies identifying appropriate environmental conditions for cis-DCE and VC transformation will be compared to field geochemcial and VOC data from site A (Wisconsin) and the Bachman Road site. This comparison will aid in determining whether an observed lack of transformation is due to inappropriate geochemical conditions or the absence of relevant microbial populations. Ultimately, this research will identify which geochemical and microbial factors should be evaluated in determining the fate of chlorinated ethenes at a site. Natural attenuation and engineered bioremediation are often the most cost-effective corrective actions for addressing groundwater contaminated with cis-DCE and VC. By conducting additional field geochemical measurements and laboratory studies to characterize biodegradation at a site, these cost-effective remedial options can be

reliably identified. The additional cost of conducting these studies, typically $30,000-40,000, is recovered by avoiding installation or long-term operation of a "pump and treat" system. In addition, information from these studies can be used in designing in situ biostimulation of cis-DCE and VC degradation.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** This project will be developing a site characterization protocol, including laboratory and field measurements, for use in feasibility studies at sites contaminated by chlorinated solvents. This protocol would complement existing documents, such as the Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water (EPA/600/R-98/128). A flow chart will be developed to aid the practitioner in identifying which chlorinated solvent transformation process may be relevant at a site. Rate constants of cis-DCE and VC transformation in microcosm studies will also be included to aid in modeling studies.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Characterization of the Aerobic Oxidation of cis-DCE and VC in Support of Bioremediation of Chloroethene-Contaminated Sites; CU-1168

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. James Gossett; Cornell University – Ithaca, NY

**FY 2000 FUNDS:** $324K

**DESCRIPTION:** The lesser chlorinated ethenes , cis-1,2-dichloroethene (cDCE) and vinyl chloride (VC), tend to accumulate at chloroethene-contaminated sites under anaerobic conditions, limiting the application of natural attenuation and enhanced reductive anaerobic in-situ treatment technologies. Aerobic degradation of lesser-chlorinated ethenes has been demonstrated; however, present understanding of the transformation potentials of cDCE and VC is limited, thus limiting the reliability of, and confidence in, natural and enhanced biological alternatives for site remediation.

This project will try to determine the distribution and metabolic capabilities of microorganisms able to mineralize cDCE and/or VC in aerobic subsurface environments. Five candidate sites will be studied, and two complementary approaches will be used to locate organisms capable of growth-coupled, aerobic oxidation of cDCE and/or VC at contaminated sites: microcosm enrichments and direct isolations from site material. Once located, the organisms will be isolated and characterized. The relationships that may exist between chloroethene degraders and ethene degraders from each site will be evaluated to determine whether the chloroethene degraders were derived from the indigenous ethene degraders. Once the relationship between ethene degraders and chloroethene degraders is clear, spatial distribution of aerobic chloroethene degradation and the distribution of chloroethene-oxidizing bacteria in the field will be assessed. The results will delineate the roles of cometabolism vs. growth-coupled degradation in the natural attenuation of lesser-chlorinated ethenes. A better understanding of these growth-coupled, aerobic oxidative pathways should expand the number of sites judged suitable for bioremediation alternatives (natural and enhanced), with potential savings to DoD in the millions of dollars.

**BENEFIT:** The results will delineate the roles of cometabolism vs. growth-coupled degradation in the natural attenuation of lesser-chlorinated ethenes. The findings are expected to shed much-needed light on the aerobic transformations of lesser-chlorinated ethenes compounds currently limiting the efficacy of natural attenuation and enhanced bioremediation of candidate sites. Results are thus expected to lead to improved site assessment (sites can be screened for existing and potential aerobic oxidative degradation activities); improved remedial-action decision-making (the effects of oxidative mechanisms can be better taken into account in modeling either natural attenuation or the effects of enhancement alternatives); and more reliable bioremediation technologies (enhancement strategies can be developed to take advantage of the aerobic transformation mechanisms). A better understanding of these growth-coupled, aerobic oxidative pathways should expand the number of sites judged suitable for bioremediation alternatives (natural and enhanced), with potential savings to DoD in the millions of dollars.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** Transition would occur by the following: (1) Incorporation of the aerobic, oxidative pathways into comprehensive fate- and-transport models, providing site managers with enhanced tools for decision-making; (2) incorporation of the findings into both Air Force and EPA natural- attenuation protocols for chlorinated ethenes; and (3) incorporation of the results into the ESTCP protocol for assessment of suitability for Reductive Anaerobic Biological In-Situ Treatment Technology (RABITT).

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Factors Affecting cis-DCE and VC Biological Transformation under Anaerobic Conditions; CU-1169

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Alfred Spormann; Stanford University – Stanford, CA

**FY 2000 FUNDS:** $247K

**DESCRIPTION:** The objective of this project is to establish a better understanding of aerobic and anaerobic transformation of cis-dichloroethene (cis-DCE) and vinyl chloride (VC). The chlorinated solvents, trichloroethene (TCE), tetrachloroethene (PCE), and carbon tetrachloride (CT) have been widely used by industry, the Department of Defense (DoD), and the Department of Energy (DOE) as solvents for cleaning. Through leakage and poor disposal practices, these solvents have become the most frequent groundwater contaminants throughout the country, causing one of the most difficult and costly contamination problems for remediation. Significant groundwater contamination with these solvents exist at DOE facilities. Most remediation approaches involve the extraction of contaminated groundwater and its cleanup at the surface through expensive physical and/or chemical methods. However, anaerobic biological processes have resulted in the natural destruction (intrinsic bioremediation) of the chlorinated solvents in some cases. cis-DCE and VC are intermediates in the biological reductive dehalogenation of PCE and TCE. Molecular hydrogen appears to be a key electron donor for these reductive processes. However, the transformation of cis-DCE to VC, and of VC to ethene is very slow. A major question raised in such biodegradation is why the process does not go to completion to ethene. How can hydrogen most effectively be funneled towards reductive dehalogenation of cDCE and VC? How can one determine at a given site the reason for lack of complete biodegradation? This proposal is for laboratory studies to better understand these questions and to develop procedures that can be used in the field for their evaluation.

The study will be conducted in five separate phases:

- ***Microorganisms, enzymes, and mechanisms involved in anaerobic reduction of cDCE and VC, and development of molecular probes.*** In this sub-project, researchers will isolate and purify the enzyme(s) calatyzing cDCE and VC reduction. They will conduct molecular analyses on the proteins and clone the encoding genes and will construct a molecular probe to monitor the genes and the process of cDCE and VC reduction, and test the probe in laboratory studies and field samples.

- ***Kinetics of cDCE and VC reductive dehalogenation.*** Project team members will experimentally evaluate a dual substrate model for cDCE and VC reduction with $H_2$ as electron donor. Team members will specially consider low substrate concentrations which are relevant for in situ transformations. This model will be tested with different dehalogenating cultures.

- ***Evaluation of potential chemical factors that may affect these processes.*** Researchers will test whether the end products of cDCE and VC reduction, ethene and ethane, as well as other chlorinated ethenes and alkanes that are frequently present at contaminated sites, will inhibit cDCE and VC reduction and determine the extent of inhibition.

- ***Development of a field procedure for estimating the presence of and the rate of release of electron donors for reductive dehalogenation.*** Researchers will develop a procedure to measure the rate of hydrogen production in a given aquifer sample and the fraction that is available for reductive dehalogenation. Once validated under careful laboratory conditions, it will be used on aquifer samples to test its usefulness for determining hydrogen availability at given sites for dehalogenation of cDCE and VC.

- ***Isolation of anaerobic cDCE and VC oxidizing microorganisms and determination of the kinetics of anaerobic cDCE and VC oxidation.*** Team members will set up enrichment cultures for anaerobic cDCE and VC-oxidizing microorganisms that use nitrate, Fe3+ or CO2 as terminal electron acceptors, respectively. Researchers will characterize the microbial community using molecular methods and attempt the isolation of pure anaerobic, cDCE and VC oxidizing strains. Relevant kinetic parameters of the mixed cultures and the pure cultures will be determined as done previously for cDCE and VC reducing cultures.

**BENEFIT:** The expected benefits of this research are the following: (1) New basic information on the mechanism of biological reductive dehalogenation of cDCE and VC. (2) Molecular probes for reductive VC dehalogenation. (3) Test of mathematical model for growth limitation at low substrate concentrations. (4) Data on inhibition of cDCE and VC reductive dehalogenation by other co-contaminants. (5) Field procedure to determine availability of hydrogen for reductive dehalogenation. (6) New basic information on microbiology of anaerobic cDCE and VC oxidation. (7) Evaluate the molecular probes that were developed with material from field sites, and correlate probe signals with reductive cDCE avd VC dehalogenation. (8) Test anaerobic cDCE and VC oxidation as engineering alternative for reductive cDCE and VC dehalogenation. (9) Evaluate potential for reductive cDCE and VC dehalogenation of related enzymes. 10) Simplify field procedure to measure electron donor release for simple use at field sites.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** The research that has been conducted over the past several years on reductive delialogenation has been used by DuPont in the application of reductive delialogenation for enhanced bioremediation of PCE and TCE at their own sites, and in conjunction with the Remediation Technology Development Forum (RTDF) studies with EPA, DOE, and DoD. The researchers have helped advise the development of enrichment cultures for bioaugmentation and on the requirements for carrying out this process. Through these cooperative studies, the results of this research will be quickly disseminated to the RTDF consortium members and others.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Assessment of the Potential for Microgravimetry in Remote Discrimination and Identification of Buried UXO; CU-1170 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Dwain Butler; U.S. Army Corps of Engineers Engineer Research and Development Center, Environmental Laboratory – Vicksburg, MS

**FY 2000 FUNDS:** $97K

**DESCRIPTION:** This project will investigate the potential role of microgravimetry for buried unexploded ordnance (UXO) discrimination and identification. Localized anomalies detected by gravity surveys are related to density contrasts and hence to mass excess or deficiency of a localized feature relative to the surrounding material. Microgravimetry involves high-resolution, high-accuracy measurements of very small anomalies in the gravitational field (of the order 10-9 of the nominal earth's gravity field), such as would be caused by presence of buried UXO. Detecting the gravitational anomaly caused by a UXO or non-UXO item will allow determination of the mass of the item. Coupled with ferrous volume estimates from magnetic surveys, UXO / non-UXO discrimination is possible.

Microgravimetry has potential applicability to localized area interrogation for UXO discrimination and identification. Microgravimetry is the only geophysical method that can give direct estimates of the actual mass of the UXO. Microgravimetry requires very careful, high accuracy measurements of the local variations of the earth's gravity field. A primary limitation to microgravity surveys in the past has been the time required to survey site elevations, make gravity measurements, and then process the data. Generally, once the microgravity data is acquired, considerable time is required to process the data and make interpretations. With the very recent emergence of near-real time microgravity, which uses digital gravimeters, dynamic "on the fly" surveying for positioning and elevation, and in-field processing, microgravimetry is now potentially applicable to problems not considered practical in the past

The study will concentrate on compiling mass and volume values for ordnance items, developing a microgravity modeling capability for a prolate spheroid geometry, generation of model gravity anomaly signatures, assessing detectability (anomaly magnitude versus depth for selected ordnance items), determining spatial sampling (measurement spacing) requirements, and assessing the potential for gravity inversion to give model parameters. The prolate spheroid gravity modeling program will require developing a complete analytical solution for the gravity anomaly on the surface above the model in a layered half-space. The solution will be valid for any orientation of the prolate spheroid model. A limited microgravity field investigation will be conducted. Microgravity measurements will be acquired above at least two buried ordnance objects, e.g., a 500-lb bomb and a 155-mm projectile. Additionally, data may be acquired above an buried, empty 55-gallon drum. There are two primary technical risks for this project:

- The realm of applicability of microgravity is too limited in terms of object size and depth of burial to play a significant role is buried UXO discrimination;

- The microgravity data acquisition is too costly and/or time-consuming to be a viable UXO discrimination tool.

**BENEFIT:** The immediate benefit is enhanced capability for discrimination of UXO from other buried objects based on the microgravity anomaly. The approach has the greatest potential for the larger buried UXO, e.g., 155-mm projectiles and larger, where the pay-off for discrimination prior to excavation is highest, due to cost of excavation and safety considerations. The long-term payoff of the research is the potential for UXO identification by joint inversion (interpretation) of gravity, magnetic and/or electromagnetic data sets.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** Results and recommendations from this exploratory development investigation will provide the basis for possible execution of the larger proposed effort, which will involve study site development, data acquisition and assessment, and the development of joint inversion capability for UXO identification.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Multiple Frequency Induction Measurements for Enhanced Buried UXO Discrimination; CU-1171 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Ernie Cespedes; U.S. Army Corps of Engineers Engineer Research and Development Center, Environmental Laboratory – Vicksburg, MS

**FY 2000 FUNDS:** $99K

**DESCRIPTION:** This project consists of developing and evaluating a novel sensing/processing system to measure the complex electromagnetic induction properties of buried unexploded ordnance (UXO) at multiple audio frequencies (30 to 30,000 Hz). The objective is to develop a low-cost, multiple frequency electromagnetic induction (EMI) device for UXO discrimination which overcomes the limitations associated with current frequency domain electromagnetic (FDEM) approaches. The approach used is to develop a prototype coil and data analysis EMI system that can simultaneously transmit multiple frequencies and rapidly measure the complex properties of buried metallic object. This approach is based on a single coil (monostatic) design which overcomes: (1) poor spatial resolution associated with current bistatic sensors, (2) poor discrimination capability of single-frequency systems, and (3) limited depth of investigation associated with bucking coil systems.

This proposed approach relies on a single coil that is energized by a composite signal that contains multiple audio frequencies of equal amplitudes and known phase. Rather than depending on physical separation of transmitter and receiver coils (bistatic methods) or using additional coils for bucking the primary field, the researchers are proposing to use the single coil for both excitation and measurement and will rely on signal processing to separate the relatively weak signals generated by buried conductive targets from the high-energy excitation signals. The success of this effort depends to a large extent on optimizing an antenna (coil) design so that materials in proximity to the antenna affect the induction of the antenna. The design should maximize the dynamic range of induction response of the antenna to varied materials. The approach to the development of this antenna is a standard engineering task and will consist of calculations and laboratory measurements to select five antenna designs that will theoretically be inherently sensitive to external materials. These designs will then be experimentally characterized using an integrated digital system. The digital control, signal generation, data acquisition and analysis system will consist of a small laptop or palm top computer, two sound cards and an audio amplifier. A two- channel excitation signal will be generated and stored as a wavetable file for each antenna. This signal will include multiple audio frequency components, and will have the characteristic that the power spectral density is flat, that is, an equal amount of power will be distributed into each frequency component. The two channels of the signal will then be amplified using low-cost Metal-Oxide Semiconductor Field-Effect Transistor (MOSFET) components and one channel will be fed into the antenna, and the other fed into a dummy load as a reference. This reference will allow for the correction of drift that is common in current EMI systems. Both output signals will then be recorded using a second sound card. The inductive reactance response as a function of frequency for the antenna in free space will be related to the response of the dummy load. This will be used to develop a transformation so that the free space spectral response of the antenna can be calculated from the signal observed in the dummy load. Since the actual signal that will be observed in the antenna is a combination of the free space response and the coupling of the radiation to the environment, the signal that is induced by the coupling of the field with the environment can be calculated. Once this signal is extracted it can then be used to calculate inductance, and ultimately the complex (inphase and quadrature) response of the environment.

**BENEFITS:** The immediate benefit of the SERDP investment will be a prototype EMI sensor that will provide performance improvements over current UXO detection/discrimination technologies. If successful, such a system could produce significant cost savings in UXO remediation projects where currently over 75 percent of the costs are due to excavating non-hazardous objects (false alarms). It is estimated that emerging

multifrequency/multichannel sensors, such as the system envisioned in this effort, will reduce the current false alarm rates by as much as 90% while maintaining high (over 90%) probability of detection.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** Assuming that the prototype system developed under the proposed effort meets performance expectations (i.e. enhanced UXO discrimination at greater burial depths than current FDEM systems), researchers will transition this technology to full scale field demonstration and follow-on transition to Corps of Engineers and commercial UXO users. Based on previous and ongoing collaborations with Geophex Ltd., lead researchers will pursue a CRADA for the commercialization and fielding of the enhanced technologies.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Novel Acoustic Technique for UXO Discrimination; CU-1172 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Thomas Bell; AETC, Inc. – Arlington, VA

**FY 2000 FUNDS:** $90K

**DESCRIPTION:** The objective is to demonstrate that a simple seismic device consisting of an impact source and a few receiver elements can be used to discriminate between buried unexploded ordnance (UXO) and clutter. Researchers will measure Rayleigh wave backscatter from suspected targets using standard Spectral Analysis of Surface Wave (SASW) technology. UXO/clutter discrimination will be based on backscatter variations with aspect angle. The basic SASW test configuration includes an impact source and a pair of receivers. The backscatter is manifested in interference effects in the frequency dependent phase shift between the signal at the two receivers. The team expects to demonstrate that, when measured over a range aspect angles relative to a suspected target, the frequency dependent phase shifts among the signals measured at the receivers contain a unique "signature" of the target that can be exploited to discriminate between buried UXO and clutter. The expected outcome of this exploratory development effort is a verification that a simple seismic device consisting of an impact source and a few receiver elements can provide data useful in discriminating between buried UXO and clutter. The basic technology is simple, rugged, and highly portable. When fully developed, researchers envision a system that can be operated by a single technician to perform cued discrimination in the field.

The standard SASW test includes an impact source that generates a spectrum of elastic waves and a pair of receivers. Researchers are interested in interference effects, due to waves scattered by the target, in the frequency dependent phase shift between the signals at the two receivers. The phase shift is calculated directly from the cross-spectrum of the signals at the two receivers. Normally (i.e., when there is nothing buried in the ground) this phase shift is used to calculate the Rayleigh wave phase speed as a function of frequency. The research team plans to demonstrate that, when measured over a range of target aspect angles, the frequency dependent phase shifts among the signals measured at several receivers contain a unique "signature" of the target that can be exploited to discriminate between buried UXO and clutter. (Since the scattering function is complex - it includes both the amplitude and the phase shift of the reflected wave relative to the incident wave - the phase shifts need to be between two pairs of receivers in order to estimate it, which means adding a third receiver to the basic SASW configuration.) The target signature will also depend on target size and depth and on the source-receiver geometry in relationship to the target (x,y) location. However, these are known and/or controlled variables. Target location, size and depth can usually be accurately estimated from the cueing sensor data, and the sensor geometry can be adjusted as appropriate.

UXO should have fairly simple characteristic scattering functions. The basic questions are (1) whether they are sufficiently different from the scattering functions of most clutter items to be useful for discrimination, and (2) whether they can be adequately estimated from data collected in the field. The critical issues that will be addressed here are how well the scattering data can be represented using a simple physics-based response model, and whether or not differences among the signatures of different types of targets are large enough compared to the variability due to reasonable uncertainties in target size, depth and location to be useful for classification and discrimination.

**BENEFIT:** The expected outcome of this exploratory development effort is a verification that a simple seismic device consisting of an impact source and a few receiver elements can provide data useful in discriminating between buried UXO and clutter. The basic technology is simple, rugged, and highly portable. When fully developed, researchers envision a system that can be operated by a single technician to perform cued discrimination in the field. This capability can significantly reduce the cost of remediating

UXO contaminated land. At present, on a typical job about 75% of remediation costs result from digging non-ordnance targets.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** The expected outcome of this exploratory development effort is a verification that a simple seismic device consisting of an impact source and a few receiver elements can provide data useful in discriminating, between buried UXO and clutter. The critical issues that will be addressed here are (1) how well the scattering, data can be represented using, a simple physics-based response model, and (2) whether or not differences among the signatures of different types of targets are large enough compared to the variability due to reasonable uncertainties in target size, depth and location to be useful for classification and discrimination. If this proof-of-concept is successful, additional research will be needed to optimize measurement configurations, develop robust processing of, algorithms and establish performance bounds for UXO/clutter discrimination.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** SAR/GPR Matched Filter Processing for UXO Discrimination; CU-1173 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. George Moussally; Mirage Systems – Sunnyvale, CA

**FY 2000 FUNDS:** $100K

**DESCRIPTION:** To demonstrate a data processing technique using measured ground penetrating radar (GPR) data that will significantly reduce the number of false positives when characterizing unexploded ordnance (UXO) contaminated sites.

This project plans to develop the use of an existing standoff GPR system operating in a SAR mode to collect data on buried UXO targets. Researchers then will process the collected GPR data into SAR imagery by incorporating radar scattering models of the general set of UXO targets of interest directly into the imaging process. Researchers hope to discriminate UXO target types by comparing the target-specific SAR imagery with conventional SAR imagery (i.e. imagery that makes no assumptions about specific target types), and then quantify the projected benefit of this processing technique to reduce the number of false alarms when characterizing UXO sites.

**BENEFIT:** Development of an effective matched filtering processing technique for use with a synthetic aperture radar (SAR) GPR offers the potential for significant improvement of UXO discrimination with this type of sensor. When coupled with the high surveying productivity of a standoff GPR, the technique could produce very useable and reliable site characterization reports featuring good detection and low false positives in a cost effective manner. Cost benefits would be derived from two key features: 1.) the reduction in false positives leading to a reduction of fruitless digs, and 2.) the high rates of survey productivity (up to 10 acres /hr for ground-based systems and up to 200 acres per hr for airborne systems) leading to reduced survey costs.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** Development of an effective matched filtering processing technique for use with a SAR GPR offers the potential for significant improvement of UXO discrimination with this type of sensor. When coupled with the high surveying productivity of a standoff GPR, the technique could produce very useable and reliable site characterization reports featuring good detection and low false positives in a cost effective manner. This discrimination capability, with acceptable detection and false alarm statistics, is also critical for use of SAR GPRs in tactical and humanitarian demining applications. Previous analyses of test site surveys performed under Army-sponsored UXO detection technologies evaluations revealed serious shortcomings, such as a large number of false positives due to a lack of discrimination capability from background/clutter effects and the interfering signals. The proposed project directly attacks this problem and offers promise of providing an practically implementable solution.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Detection and Classification of Buried Metallic Objects; CU-1174 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. H. Frank Morrison; Lawrence Berkeley National Laboratory – Berkeley, CA

**FY 2000 FUNDS:** $100K

**DESCRIPTION:** Because detection and identification of metallic minerals is an important part of geophysical exploration, researchers have developed considerable expertise in the use of numerical modeling algorithms to simulate the response of electrically conducting objects to various types of detectors. This project will modify existing computer programs to study the behavior of a variety of landmine and unexploded ordinance (UXO) targets buried in different positions and ground conditions. This will give quantitative criteria for evaluating the effectiveness of various land-based metal detection systems. The results will enable the researchers to propose the design of a new system which, in addition to locating targets, will be optimized to determine their size, shape and orientation and the depth at which they are buried. This system will be sensitive enough to suggest physical characteristics of buried objects, including their electrical conductivity, magnetic permeability, and the presence of electrically insulating (plastic) shells surrounding them. This information will enable a user to accurately discriminate between landmines, UXO and spurious metallic debris.

This project proposes to use numerical model simulators, which have been developed by geophysicists in the mineral exploration community, to design and prototype an active electromagnetic system for detecting and characterizing the metal content of mines and UXO against a background of geologic materials and other metal objects. An optimized metal detector will be developed with the capacity to determine the following physical properties of a buried metal object:

- Depth
- Size, shape and orientation
- Electrical conductivity
- Magnetic permeability
- State of contact with the ground (insulated or not).

The design will be adapted to a portable, hand-held, battery powered system with a user friendly display of the target response, and also to a larger mounted system which can be used to search the broad area in front of a vehicle. The general design will include a variable-frequency transmitter which will produce a known magnetic field. This primary field will induce electric currents in the target which will then produce magnetic fields which will be measured by the receiver. The results of numerical simulation of target responses will be used to tune the system, determine the optimum frequency range and transmitter-receiver configuration to produce the largest and most diagnostic response of the target using the smallest expenditure of power in the transmitter.

**BENEFIT:** The mineral exploration community has used electromagnetic (EM) methods to detect the electrically conductive metallic minerals which are the source of much of the world's supply of copper, lead, zinc and gold. Because of the complexity and economic importance of mineral deposits, a vast amount of research has been devoted developing methods of finding and characterizing them. Much of the research of the geophysical community has been to develop a quantitative understanding of the characteristic behavior of many different kinds of metallic objects located in a variety of positions and backgrounds. A new generation of electromagnetic sensing systems is now possible that could screen large areas or provide high-resolution classification of particular targets. Drawing on extensive experience with large scale mineral exploration EM systems, numerical simulators for quantitative modeling, and recent work in model based

classification algorithms the research team proposes a computer based design of an optimum system specifically to meet the needs UXO Detection and Discrimination."

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION**: This proposed system may replace the object-specific metal locators now in use worldwide. Project researchers will begin immediately identifying suitable partners for transitioning the design to an implementation and fabrication group. To this end the researchers plan to sponsor a small workshop of those individuals currently involved in developing EM systems for UXO detection.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Fe(O)-Based-Bioremediation of RDX-Contaminated Aquifers; CU-1175 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Pedro Alvarez, P.E., DEE; The University of Iowa – Iowa City, IA

**FY 2000 FUNDS:** $100K

**DESCRIPTION:** Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) is the British code name for Research Department Explosive. RDX is toxic to humans and a variety of organisms, and is classified as a Class C (possible human) carcinogen by the US EPA. Toxicity studies have led the Surgeon General to recommend a 24-h maximum RDX concentration of 0.3 mg/l to protect aquatic life. The Office of Drinking Water has set a limit for lifetime exposure to RDX at 0.1 mg/l. Because of its recalcitrance to microbial degradation, low tendency to volatilize and high mobility in aquifers, clean-up of RDX contaminated sites is a challenging problem. Current practices to remove RDX from contaminated soil include incineration, composting, alkaline hydrolysis/oxidation, and aqueous thermal decomposition. However, these ex situ approaches are not cost-effective to treat large volumes of contaminated groundwater. In addition, complete destruction of RDX is not always achieved, giving rise to the possibility that products of equal or greater toxicity accumulate. This project is planning to develop a new and efficient method to remediate RDX-contaminated aquifers. This method is based on combining a novel chemical process [reductive treatment with Fe(O)] with a promising bioremediation approach (in situ reactive zones). This integrated Fe(O)-microbial system should improve the capability and reduce the cost of RDX remediation efforts.

The specific goal of this one-year project is to delineate the applicability and limitations of biologically-active Fe(O) barriers to manage RDX plumes. To achieve this goal, the researchers need to answer numerous questions related to the feasibility of Fe(O)-based bioremediation, e.g., what is the fate of RDX in combined microbial-Fe(O) treatment systems? Is the combination of Fe(O) with anaerobic bacteria synergistic in terms of contaminant removal rates? IS there a need to add acclimated microorganisms, or will an indigenous hydrogenotrophic consortium eventually develop around Fe(O) barriers to fill a metabolic niche associated with cathodic depolarization and RDX biodegradation? How long does it take for such a natural consortium to develop?. Other questions should be addressed to obtain basic criteria for process design and operation, e.g., what rate law does RDX removal follow? What should be the Fe(O) surface area concentration to optimize desirable biogeochemical interactions? How long does Fe(O) or the added bacteria remain active? How do pH, temperature, and redox conditions affect RDX removal kinetics and end product distribution? Can thinner barriers be used as a pre-treatment step to enhance RDX mineralization by (downgradient) indigenous microorganisms? How do microorganisms affect the hydraulic performance and long-term reactivity of the barrier?). The project plans to complete these specific tasks to answer the questions from above. (1) Compare the fate and degradation kinetics of 14C-labeled RDX in soil microcosms amended with Fe(O), anaerobic mixed cultures, both, or none. (2) Identify soluble degradation intermediates and end products for each treatment. (3) Determine if indigenous aquifer microorganisms colonize the Fe(O) surface, and how microbial growth and (cathodic) $H_2$ gas consumption affect the permeability of flow-through aquifer columns. (4) Determine how hydraulic loading of the columns affects RDX removal efficiency.

**BENEFIT:** An integrated microbial-Fe(O) treatment systems may offer significant advantages over approaches where either process is used alone. Specifically, bioaugmentation of Fe(O) barriers with pre-acclimated anaerobic bacteria will enhance the treatment of RDX plumes by increasing both the rate and extent of transformation and by yielding a more favorable product distribution when compared to treatment with Fe(O) alone or anaerobic bacteria alone. This synergism is hypothesized to be due to several factors. Fe(O) corrosion rapidly induces anoxic conditions that favor RDX biotransformations. The production of cathodic (water-derived) hydrogen by Fe(O) corrosion would increase the availability of an excellent primary

substrate to support microbial reduction of RDX and the further degradation of some dead-end products that accumulate during abiotic reduction by Fe(O). Hydrogenotrophs could also remove the passivating cathodic $H_2$ layer from the Fe(O) surface, which could enhance the reactivity of Fe(O) (i.e., cathodic depolarization). Microbial consumption of $H_2$ gas bubbles may also enhance the permeability of the barrier to offset any decrease in permeability resulting from microbial growth. Alternatively, the reduction of RDX by Fe(O) enhances its subsequent biodegradability. Thus, a sequential scheme where a pre-treatment Fe(O) barrier is followed by down-gradient bioremediation of any products that break through might also be a viable alternative to clean up RDX contaminated aquifers.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** This project will seek to collaborate with other scientists and contractors at DoD sites to conduct controlled field demonstrations. Possible Superfund sites for demonstrating this technology include the Iowa Army Ammunition Plant (IAAP) at Middletown, IA, and the Nebraska Ordnance Plant (NOP) in Mead, NB. Field technology transfer and trial will be pursued after obtaining a better understanding of the applications and limitations of the pertinent processes.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** In-Situ Remediation of Explosives Contaminated Groundwater with Sequential Reactive Treatment Zones; CU-1176 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Paul Tratnyek; Oregon Graduate Institute – Beaverton, OR

**FY 1999 FUNDS:** $100K

**DESCRIPTION:** The objective of this project is to develop a sequence of reactive treatment zones (SRTZ) for treating groundwater contaminated with nitro aromatic explosives such at TNT, RDX, Tetryl, etc. The SRTZ will consist of (1) an Fe(O) permeable reactive barrier (PRB) to reduce nitro groups to amines, followed by (2) an oxidation cell that immobilizes the amines by oxidative polymerization. This project will evaluate methods of treating the effluent from an FePRB by in situ chemical and/or enzymatic oxidation. Emphasis will be placed on optimizing the (permanent) sequestration of Nitro Aromatic Compounds (NAC) by oxidative polymerization and coprecipitation with iron oxides in an open cell. A variety of oxidants (air, O2, $H_2O2$), delivery systems (sparging, direct injection, passive infiltration), and process variables (flow rate, pH, carbonate, iron) will be tested at the column scale. Design criteria for pilot and full scale SRTZs will be developed using column test results and computer modeling.

This project will evaluate methods of treating the effluent from an FePRB by in situ chemical and/or enzymatic oxidation. Emphasis will be placed on optimizing the (permanent) sequestration of NACs by oxidative polymerization and coprecipitation with iron oxides in an open cell. A variety of oxidants (air, O2, $H_2O2$), delivery systems (sparging, direct injection, passive infiltration), and process variables (flow rate, pH, carbonate, iron) will be tested at the column scale. Design criteria for pilot and full scale SRTZs will be developed using column test results and computer modeling.

**BENEFIT:** The project is designed to provide an efficient transition into one of two promising paths for further development of this technology: (1) a pilot-scale demonstration in the PRB test facility at the Oregon Graduate Institute, or (2) a pilot-scale field demonstration at a DoD field site. The latter may be preferred, but details can not be established for such a plan until a site is selected and collaborations have been established with DoD/DOE scientists and engineers who are involved with the site. Some details can be provided, however, on how a pilot test could be preformed at one of OGI's LEAP tanks.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** The project plans to transition into one of two promising paths for further development of this technology: (1) a pilot- scale demonstration in the PRB test facility at the Oregon Graduate Institute, or (2) a pilot-scale field demonstration at a DoD field site. The latter may be preferred, but details can not be established for such a plan until a site is selected and collaborations have been established with DoD/DOE scientists and engineers who are involved with the site.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Novel Approach for Stimulating Reductive Dechlorination; CU-1177

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Todd Wiedemeier; Parsons Engineering Science, Inc. – Denver, CO

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** Chlorinated solvents in groundwater are one of the DoD's biggest environmental problems. Reductive dechlorination is a known mechanism for the biodegradation of many chlorinated solvents. Unfortunately, no commercially viable and widely accepted process for in situ bioremediation of chlorinated solvents has emerged. The VegOil process uses inexpensive, food-grade vegetable oil directly injected into a contaminated aquifer to stimulate reductive dechlorination of chlorinated solvents.

Laboratory studies of vegetable oil as a food source for anaerobic dechlorination will be performed. These studies have two purposes: (1) to determine the anaerobic breakdown products of the oils - most importantly, the dynamic profile of hydrogen that results and the fractions of reducing equivalents that are channeled to dechlorination versus competing methanogenesis and any potentially problematic breakdown products of a bromonated oil; and (2) to assess the nutritional sufficiency of the oils. An anaerobic mixed culture will be employed in these studies, consisting principally of a well characterized dechlorinator, various fatty-acid fermenters, acetotrophic methanogens, and hydrogenotrophic methanogens. Aliquots of the culture will be anaerobically transferred to sealed serum bottles and amended with the following treatments: (a) Perchloroethylene (PCE) only; (b) PCE + oil; (c) PCE + oil + yeast extract + vitamin mixture; and (d) PCE + yeast extract + vitamin mixture. The time-course profiles of volatile fatty acids, hydrogen, chloroethenes, and methane will be monitored after setup. If, as expected, successful degradation of oils and reductive dechlorination can be sustained, then semi-continuous operation will be maintained with regular re-feeding, wasting, etc. Bottle-types (a) and (d) will serve as controls to allow the role of the oils to be assessed. It is anticipated that three to four types of oil will be tested and that these studies will run for approximately six to nine months.

**BENEFIT:** Reductive dechlorination is a known mechanism for the biodegradation of many chlorinated solvents. Several approaches for stimulating this process have been demonstrated, and some are being commercialized. Unfortunately, no commercially viable and widely accepted process for in situ bioremediation of chlorinated solvents has emerged. The VegOil process is designed to create the redox and electron donor conditions necessary to promote microbial reductive dechlorination of chlorinated solvents in a cost effective manner. Vegetable oil is a food-grade product that can be injected directly into a contaminated aquifer. The VegOil process is designed to create the redox and electron donor conditions necessary to promote microbial reductive dechlorination of chlorinated solvents. To date, no commercially viable and widely accepted process for in situ bioremediation of chlorinated solvents has emerged. Vegetable oil is an inexpensive, innocuous, food-grade carbon source that is not regulated by the EPA. Because vegetable oil is a non-aqueous phase liquid (NAPL), the potential exists that a single, low-cost injection could provided sufficient carbon to drive reductive dechlorination for many years. This will significantly lower operation and maintenance costs compared to aqueous phase injection, and will allow injection of a much greater quantity of carbon than solid phase emplacement.

**ACCOMPLISHMENTS:** Laboratory studies were initiated.

**TRANSITION:** Laboratory studies will be performed to determine the suitability and types of vegetable oils be used for future field testing of the technology. Upon completion of the work a report detailing the methodology and results of the laboratory studies will be prepared and transitioned to AFCEE who is funding complementary pilot-scale field tests of the VegOil technology. It is anticipated that the project will be fully completed by 30 September 2000.

# APPENDIX B
## Compliance Project Summaries

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# PROJECT SUMMARY

**PROJECT TITLE & ID:** Kinetics of Supercritical Water Oxidation; CP-364

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Steven F. Rice; Sandia National Laboratory – Livermore, CA

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** The objective of this project was to develop a supercritical water oxidation (SCWO) technology to treat aqueous wastes. SCWO is an emerging technology under development at several laboratories, including Sandia National Laboratory, for the treatment of hazardous wastes such as obsolete chemical munitions, mixed wastes, and naval shipboard excess hazardous materials. Understanding of the rates and mechanisms of reactions in supercritical water was limited to a handful of empirical rate expressions for very simple chemicals. These expressions were of limited use in the formulation of predictive models of SCWO for the design and operation of large-scale waste processing equipment. To be applicable as design tools, the models needed to be based on elementary reaction steps or, at minimum, a detailed quantitative mechanistic description incorporating all the key fundamental reactions. Basic research was needed to improve the ability to predict reaction rates in supercritical water. The project was designed to result in a user-friendly, computer-based model that could predict reaction rates and conversion efficiency for a wide range of waste feeds and reactor conditions.

**BENEFIT:** The SCWO process, operating at two orders of magnitude greater density than atmospheric gaseous combustion, provides high reaction rates at moderate temperatures. The chemical engineering literature contains results of studies of SCWO measuring destruction efficiencies for a variety of waste chemicals and mixtures. Some of these data can be used to generate empirical, global kinetic rate expressions for a select list of simple species. However, the in-situ measurements used in this project, particularly on intermediates, lead to valuable information for predictive model development. The improved understanding of reaction rates and the kinetic models developed by this project have produced advanced strategies for reactor design and improved methods for commercial system optimization.

**ACCOMPLISHMENTS:** This project developed oxidation rates for common organic compounds in supercritical water. These data provide the basis to develop a model (combustion-based as opposed to liquid-phase oxidation) to be used as a design engineer's tool for testing the effects of reactor design changes and producing advanced strategies for large-scale system optimization.

This project focused on the development of a detailed chemical kinetic description of SCWO within the context of practical applications for the Department of Defense (DoD) and Department of Energy (DOE). The oxidation rates of a variety of prototypical organic compounds have been studied and quantitative elementary reaction models have been developed that can accurately reproduce the experimental results. Significant progress was been made in accounting for the effects of mixtures of different types of organic species a well, setting the stage for implementation of these kinetic models into actual engineering design computational tools.

**TRANSITION:** In addition to presentations at technical meetings and publication in peer-reviewed literature, results from this project are made available to a wide distribution within the SCWO technical community. Additional transition will occur with indirect support on leveraged projects with the Defense Advanced Research Projects Agency (DARPA) and the Office of Naval Research (ONR) for shipboard waste, with the U.S. Army Applied Research, Development and Engineering Center's (ARDEC) Pine Bluff Arsenal Unit, and at the U.S. Army Aberdeen Proving Ground. In coordination with ARDEC on the Environmental Security Technology Certification Program (ESTCP)-supported Pine Bluff Arsenal SCWO plant start-up project, the investigators assisted with the design and installation of the SCWO reactor.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** National Environmental Education and Training Center (NEETC); CP-819

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Raymond Lovett; National Environmental Education & Training Center – Indiana, PA

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** New environmental technologies are often designed for efficacy with little consideration given to the safety of the technology to an operator, a maintenance worker or the community. As a result, significant time and energy is spent on re-engineering technologies to address health and safety issues. This project sought to (1) create, as an effective, deliverable tool for technology developers, a knowledge-based prototype system, known as TEXPERT, to evaluate and incorporate health and safety concerns into the design of environmental technologies, and (2) improve health and safety information and its dissemination during technology deployment.

TEXPERT was implemented on the Internet. This system provides new technology developers with access to an "occupationally and environmentally focused total system design assessment tool" through an Internet site that is linked to databases and software tools (using Environmental Protection Agency formats) on health and safety associated with known technologies, risk assessment, preliminary hazard recognition and analysis, fault-tree analysis, and job safety analysis.

**BENEFIT:** This health and safety evaluation tool, coupled with existing "engineering design and management tools" will assist designers and technology "gatekeepers" in evaluating and assessing health and safety issues in a focused, systematic way during technology development. It will lead to a consideration of "downstream" worker and environmental safety and health implications associated with field (or production) use of innovative technology, and minimize the occurrence of health and safety concerns before and during end-user implementation.

**ACCOMPLISHMENTS:** The National Environmental Education and Training Center, Inc. began evaluating a field environmental technology test and acquired a video of the technology installation. The video was evaluated for health and safety aspects in preparation for the production of a test protocol. A draft CD of training methods was produced and is the backbone for the design of the final product. A project to evaluate ship scrapping began and a memorandum of agreement (MOA) was signed with the U.S. Navy to begin acquisition of data to make the process more cost effective and environmentally sound.

**TRANSITION:** Transition of this technology consists of: full implementation of an expert system that is available on the Internet or on diskette; demonstration at two technology development sites; and integration with a similar Department of Energy (DOE) program. Implementation of an outreach program via the Internet is also planned.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Development of Non-Thermal Plasma Reactor Technology for Control of Atmospheric Emissions; CP-1038

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Louis Rosocha; Los Alamos National Laboratory – Los Alamos, NM

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** The overall objective of this project was to evaluate and develop new non-thermal plasma (NTP) reactor technologies for Department of Defense (DoD) air emissions control applications while providing a basis for selecting the most appropriate NTP technology. This was accomplished by evaluating the performance of prototype and pilot-scale NTP reactors (i.e., corona, dielectric barrier, and electron beam) for Nitrogen Oxide (NOx) and Hazardous Air Pollutant (HAP) abatement and specialized Volatile Organic Compound (VOC) control. The development of an efficient, reductive-model NOx processor was a key goal.

**BENEFIT:** All organizations within the DoD, the Department of Energy (DOE), and industry affected by the need to control emissions of NOx, HAPs, and VOCs will benefit from the development of a flexible technology for emissions control and a basis of selecting the most appropriate technology for specific needs. With the successful development and implementation of NTP technology, present and planned DoD activities can proceed without deleterious environmental impacts or major compliance-issues and cost escalations. Particular technical impacts from this project include an increase in the efficiency of electric-discharge NTP (by control of discharge physics and plasma chemistry) and the potential for development of low back-pressure, filterless, scrubberless NOx control equipment using reductive mode processing, effected by improved electrical driver technology. Also, other VOC-abatement technologies are not yet fully proven, therefore, NTP can be a promising back-up in some cases.

**ACCOMPLISHMENTS:** The field-demonstration equipment architecture has been finalized and is a hybrid system, consisting of a corona radical shower (CRS) NTP reactor plus a catalyst bank and electrostatic filters (to capture the de-NOx treatment products). This hybrid architecture is required because of the need to handle very low NOx concentrations (< 10 ppm) in cruise missile engine exhaust (which will be used in the field test). The catalysts probably will not be required for jet engine test cells (JETC), which have NOx concentrations on the order of order 50 ppm. Small-scale pilot equipment design iterations continue to simplify and reduce the cost of the field demonstration. Fabrication drawings have been finalized for several plasma reactor components, bids have been obtained on these, and orders have been placed with machine shops for fabrication. Final designs and drawings are progressing for other components. Final testing of computational fluid dynamics (CFD) model of NTP channel-flow reactor including full chemical kinetics mechanism and a full complement of closely-spaced streamers has been completed.

**TRANSITION:** The transition plan for this project involves coordination with users, coordination with industry, and full-scale implementation within DoD/DOE. User coordination includes: Air Force NOx abatement projects, JETC and diesel engine NOx abatement, VOC control at Tinker Air Force Base, emission control for the "Burn Box" at the Army's Aberdeen Test Center, and multi-agency interfacing via Los Alamos Environmental Management (EM) and DoD Program Managers. Industry coordination includes existing technology-commercialization Cooperative Research and Development Agreements (CRADAs) with the Electric Power Research Institute (EPRI) and High Mesa Technologies (HMT), potential future CRADAs with HMT and Environmental Elements, and Los Alamos Industrial Partnership Office promotion of industrial interaction. An industrial partner will be identified during the transition phase of this project.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Development and Integration of Laser-Based Sensors for VOC/NOx and Metals Emissions Monitoring; CP-1060

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Scott Bisson; Sandia National Laboratory – Livermore, CA, and Dr. Meng-Dawn Cheng, Oak Ridge National Laboratory – Oak Ridge, TN

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** The objective of this project was to develop a combined laser-based system for monitoring volatile organic compounds (VOC), nitrogen oxides (NOx), and metals for compliance with the Clean Air Act Amendments of 1990. For gaseous pollutants, an infrared (IR) spectrometer based on the new, periodically-poled lithium niobate (PPLN) laser technology was used. For metals emissions monitoring, laser induced breakdown spectroscopy (LIBS) was employed.

For development of the IR Spectrometer, the tunability, spectral bandwidth, and oscillation threshold of the PPLN source will be characterized. Given the wide range of species to be detected and the fact that the absorption spectra span the infrared, broad tunability will be essential. The detection sensitivity will also be optimized through the use of acoustically resonant cells.

For development of the portable LIBS (PLIBS), currently available solid-state diode lasers will be identified and evaluated for long-term operation. The feasibility of using a solid-state laser for plasma ignition and spark generation will be investigated. If successful, this would reduce the physical dimension and weight of the LIBS system substantially and move one step closer to the portable unit proposed. Other compact lasers such as a diode-pumped Nd:YAG laser will also be evaluated.

**BENEFIT:** If successful, this technology would allow, for the first time, near real-time, in-situ analysis for monitoring a wide range of chemical species (metals and gases) with higher sensitivity than previously achievable. There are also potential applications in process control and atmospheric chemistry research. Moreover, the compact size of this new system is attractive, making a portable system a possibility, and its cost is anticipated to be competitive with many conventional, laboratory analytical services.

**ACCOMPLISHMENTS:** Two aerosol beam focusing modules, with different flow configurations, were successfully fabricated. Digital signal processing and control algorithm sets were implemented on a laptop control module. Long range scans (>100cm-1) have been demonstrated. A new photoacoustic cell was assembled and installed resulting in improved sensitivity and response time. Project research results were presented at the Conference on Lasers and Electro- Optics (CLEO), the world's largest laser conference. Truly continuous tuning with a second PPLN laser system was demonstrated and paint, paint solvents and catalysts were characterized with a Gas Chromatography Coupled Mass Spectroscopy (GCMS) system. This characterization was necessary for the field test at a LLNL paint shop. The following has been accomplished during the field test: 1. GCMS analysis of paint shop emissions using Environmental Protection Agency (EPA) sampling and analysis methods; 2. Calibration of the photoacoustic spectrometer with VOC calibration gases; 3. Optimization of the system by reducing systematic noise to the 1% level.

Additional accomplishments at Oak Ridge National Laboratory include: filing a patent, conducting rigorous diagnostics on the portable LIBS system with mono-dispered solid particles of 10,000, 4000, 2500, 1500, and 25 nm in diameter, demonstrating that LIBS can achieve a detection level of 5-6 particles per cc of absolute mass, and developing a new kinetics module to improve the digital data acquisition speed to acquire the optimal delay time while on-line.

**TRANSITION:** Two important collaborations are being established. The first involves work with a group (leaders in gas-phase photoacoustic spectroscopy for environmental and biological applications) from the

Catholic University of Nijmegen in the Netherlands. The second involves Coherent Inc., a laser company that is developing a laboratory PPLN laser. These collaborations will accelerate this effort and open up a potential technology transfer path for a fieldable photoacoustic system.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Detect and Identify Multiple Hazardous Air Pollutants (HAP) at Extended Distances; CP-1061

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Antonio Ting; Naval Research Laboratory – Washington, DC

**FY 2000 FUNDS:** $215K

**DESCRIPTION:** The objective of this project is to develop a new class of sources for active remote sensing of hazardous air pollutants (HAP) using ultra broadband (UB) radiation, and techniques for their detection and identification. UB radiation can provide the necessary illumination required for active remote sensing to allow real-time ranging and identification of HAPs at extended distances.

The mechanism for the generation of UB radiation is based on self-phase modulation of picosecond laser pulses in a nonlinear optical medium. Continuous UB radiation can be generated with extremely high efficiency and high average power by beating two laser beams with slightly different frequencies. The bandwidth of the radiation can extend from the optical to the Infrared (IR) regime. The source size of the UB radiation is extremely small, which allows for beaming the radiation over extended distances of several kilometers.

The generation of UB radiation in various nonlinear materials is being evaluated using existing laser facilities at the Naval Research Laboratory (NRL). Lasers with optical and near-IR wavelengths are being used to generate UB. The conversion efficiency and bandwidth will be optimized by selecting the appropriate nonlinear medium. The quality of the UB radiation beam is being measured and its propagation in air characterized. The methodology and diagnostics necessary to evaluate the UB spectrum are based on hyperspectral imaging techniques that are being developed at NRL. Proof-of-principle experiments on active remote sensing is being performed, and data reduction techniques for analyzing complex spectral signatures is being studied.

**BENEFIT:** The application of UB radiation sources to remote sensing can lead to the identification, ranging, and detection of HAPs at extended distances through simultaneous spectral response from various HAPs. It will allow the tracking of nitrogen oxides (NOx), chlorine oxides (ClOx), and sulfur oxides (SOx). UB radiation is also especially valuable during night-time monitoring when sunlight is not available for conventional remote sensing methods. A system of active remote sensing using UB radiation will benefit efforts for continuous, real-time identification of HAPs that are of concern to the Department of Defense (DoD).

**ACCOMPLISHMENTS:** An experimental set up was configured in which UB radiation generated in 300 meters of optical fibers was sent through a gas cell containing acetylene gas at various pressures. Absorption structures in the UB radiation were clearly visible using the Indium Gallium Arsenide (InGaAs) line scan. The 2D Indium Antimony (InSb) camera provides the spectra from both the absorbed and unabsorbed UB radiation for the same shot. This eliminates the shot to shot fluctuations in the UB radiation. Multiple shot data were analyzed by the Kalman filter signal processing technique developed in this project. The results of the Kalman filter program closely matched the experimental values of the gas pressures. Experiments with other gases such as methane are ongoing.

The propagation of broadband radiation emitted from the end of a multi-mode optical fiber was studied using a 10 inch, F/4.5 aperture, Newtonian reflective telescope. Good propagation characteristics of the broadband radiation due to the small source dimensions of an optical fiber were demonstrated. A gas cell is under construction for mixing known proportions of test gases with air to study their absorption spectra using the UB radiation. A second InGaAs linear detector is being used with a spectrometer to monitor the outgoing UB radiation from the telescope.

**TRANSITION:** The Transition Plan includes further development and demonstration within SERDP, including testing of the device in a field environment. Additional transition could occur in Small Business Innovation Research (SBIR) Phase I and II leading to Cooperative Research and Development Agreement (CRADA) Programs. This signal processing algorithm for the identification of HAPs with UB radiation was presented at an International Conference on Signal and Image Processing.

The UB radiation source technology and the signal processing algorithm developed in this program have been recognized by the Research Support Instruments, Inc. of Lanham, MD, in their effort to submit a SBIR proposal to Defense Advanced Research Projects Agency (DARPA).

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Plasma-Assisted Catalytic Reduction of NOx; CP-1077

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Joseph Wander; Air Force Research Laboratory – Tyndall Air Force Base, FL

**FY 2000 FUNDS:** $425K

**DESCRIPTION:** The objective of this project is to further develop and optimize selective catalytic reduction (SCR) technology by using a non-thermal plasma (NTP) to assist with the catalytic destruction of nitrogen-species contained in gaseous emissions. It will extend bench-level observations of the cold-plasma-induced catalyzed chemistry of propene in simulated combustion-exhaust gases to include mixtures of fuel constituents common to JP-8 in actual combustion exhaust.

In the SCR process, the destruction of partially oxidized nitrogen-based contaminants found in combustion-exhaust emissions proceeds by oxidation of nitrogen-species to $NO_2$ which are subsequently reduced to $N_2$ by a hydrocarbon. By choosing oxidation-catalyst components that pre-convert NO fully to $NO_2$, mechanically mixed with reduction-catalysts, catalysts previously regarded as inactive for nitrogen oxide (NOx) reduction have been shown to become efficient. Bench-scale studies on a simulated exhaust gas using propene as the reductant have accomplished a very efficient conversion of the mixture to $N_2$, $CO_2$, and water. The main technical challenge is maintaining high efficiency for NOx reduction when flow-rates are increased to pilot-scale (50 cfm), and when diesel fuel (and kerosene-like liquid hydrocarbons) is used as the reductant. The project is assembling and evaluating a pilot-scale NOx- and particulate- control device implementing the refined plasma-assisted SCR concept to treat exhaust flow from a Cummins diesel engine generator. Data from this pilot-scale test will support estimates of the cost and performance of operating this technology as a full-scale emission control process and determine the extent of control that can be realized.

The focus is to characterize and optimize the atomization and mixing of the liquid hydrocarbon reductant. Other options for optimizing the injection of the liquid hydrocarbon into the de-NOx reactor are being investigated. A gas chromatograph system will be installed and used, together with a flame ionization detector and a Fourier Transform Infrared Spectrometer, to analyze the mixing and speciation of the fuel during the injection process. The NOx reduction efficiency will be characterized as a function of the engine power consumption, fuel consumption, and exhaust flow rate through the de-NOx reactor.

**BENEFITS:** This project will provide a wider range of SCR catalysts with improved efficiency and durability, which when used in combination with a non-thermal plasma will eliminate some of the deficiencies of a purely catalytic approach. The specific benefits yielded will be:

- The option to operate diesel-powered equipment at greater than 95 percent of baseline performance and fuel efficiency while emitting less than 10 percent of baseline pollutants.
- Definitive determination about economic feasibility of catalytically augmenting plasma-induced chemical conversions.
- Advancement of the state-of-the-art in SCR and other catalytic processes.

**ACCOMPLISHMENTS:** Assembly of the full-scale plasma processor unit, capable of 9,000 standard liters per minute (SLPM) flow and 5 kW power, has been completed. The baseline for full-flow testing of the Cummins B5.9 diesel engine generator set is based on a maximum flow of 8,760 SLPM at 100% load on the engine. It has been established that an energy density of about 20 J/L is required from the plasma processor. This requires a plasma processor capable of exciting the plasma with at least 3000 watts.

A full-scale NOx control system was completed and successfully operated to treat the full exhaust flow from a Cummins 100-kW generator set. This unit is typical of aircraft ground support equipment, and representative of medium-sized diesel engines used to power mobile and stationary heavy equipment. Installation of the piping, plasma processor, and catalyst bed was completed. The engine was operated at up to maximum capacity and the pressure drops across the major components were measured.

The entire full-scale NOx control system, including diagnostics, was successfully operated on the engine test stand. When kerosene is injected into the exhaust stream, NOx removal commenced and is improved upon addition of the plasma. An initial removal figure of approximately 55 percent was found for the final conditions. This result is consistent with previous bench-scale and slipstream tests that demonstrated attainment of Department of Energy's (DOE) criterion of at least 50 percent NOx removal at less than 5 percent net fuel penalty for heavy-duty diesel engines. An engineering cost estimate for a full-scale system was completed.

**TRANSITION:** The technology is expected to be ready for transition to an Environmental Security Technology Certification Program (ESTCP)-type demonstration and evaluation of a scaled-up prototype within two years. A commercial partner, Cummins Engine Co., is committed to deploying this technology as soon as it is technologically and economically viable.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Enzymes for Degradation of Energetic Materials and Demilitarization of Explosives Stockpiles; CP-1078

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Steve Goheen; Pacific Northwest Laboratory – Richland, WA

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** The objective of this project is to develop a safe, economical and environmentally sound process in which biocatalysts (enzymes) can be used for degradation of energetic materials with an option of converting degradation by-products into value-added materials.

The overall technical approach for the proposed research evaluated the transformation of munitions such as TNT, RDX, and HMX in different forms (compositions A, B, C, and D; H-6; Tritonal) to intermediate products using enzymes. The intermediate products, in some cases, were expected to have reduced or no toxicity and thus will be evaluated for their approval for disposal by the regulatory agencies. In other cases, the intermediates could be used as a feed stock in the chemical industry or destroyed to carbon dioxide and water using microbial and/or chemical processes. The toxicity of the intermediate products and final products was evaluated.

The initial focus was on the kinetics and mass transport issues involved in explosives (e.g., TNT) degradation by enzymes under heterogeneous conditions. A specific emphasis was to understand the difference between the conversion of explosives by enzyme catalysis in a heterogeneous solid-liquid system compared to a normal heterogeneous catalytic aqueous system. Different combinations of enzymes, mediators, and reaction environments were investigated.

**BENEFITS:** Special features of the proposed enzyme technology include: excellent kinetics, no special equipment requirements, enzyme effectiveness under diverse reaction conditions (i.e., solvents, high concentration of explosives, etc.), very high reactivity per unit weight of catalyst, simple operating process, remote locations accessible with enzyme spray, effectiveness at room temperature and atmospheric pressure, low operating and production costs, and potentially mobile systems that allow flexibility for demilitarization operations.

**ACCOMPLISHMENTS:** 4-HADNT, 4-ADNT and 2-ADNT were identified as products formed by oxyrase in the presence of TNT. HMX, RDX and TNT are all mineralized by sodium chlorite, with TNT being mineralized at 70°C and over long reaction times. A clearer understanding of the enzymatic degradtion of TNT has been developed. Using the enzymes FNR and glucose-6-phosphate dehydrogenase in the presence of TNT formed the products 4-HADNT and ADNT. It appears that oxidoreductive enzymes form either 4-HADNT or 4-HADNT + ADNT. These products have been confirmed by mass spectrometry.

The toxicity of TNT and its metabolites has been quantified. TNT was reacted with xanthine oxidase to completion so that all TNT had been reduced. The toxicity of the products and metabolites were assessed using a *Ceridaphnia dubia* assay. In parallel, toxicity was measured by the Microtox Assay. In both assays it was found that TNT conversion with xanthine oxidase led to a reduction in toxicity to microorganisms.

Two patents, one for "Combined Enzymatic and Microbial Method for Destruction of Explosives" and another for "Method for Transformation of Nitroaromatics by Redox Enzyme" were submitted for this project.

**TRANSITION:** A business relationship with an enzyme provider, Genencore International, was established. Additionally, a polymer scientist from Ethyl Corporation will perform a preliminary assessment of industrial applications of TNT-derived amines. One patent for the transformation of explosives by potassium superoxide was submitted and at least two manuscripts will be written. The transition plan also includes a site demonstration with companies involved in demilitarization activities at the Naval Surface Warfare Center-Indian Head, the U.S. Army Defense Ammunition Center, and the Department of Energy Pantex Plant. In an on-going effort to transfer this technology to the end user, the technical approach and preliminary results were presented at the Global Demilitarization conference. This project has also received considerable coverage by the media (i.e., television, magazines, and journals).

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Hypergolic Non-Detonative Neutralization in Production and Demilitarization; CP-1079

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Ms. Pamela Walker; Sandia National Laboratory – Albuquerque, NM

**FY 2000 FUNDS:** $455K

**DESCRIPTION:** The objective of this project is to develop an innovative, alternative technology to replace open burn/open detonation (OB/OD) operations for the destruction and disposal of obsolete, excessive, and off-specification energetic materials. The initial focus of this project is to develop effective reagents and to understand the underlying chemistry for reacting the energetic materials with a hypergolic chemical, which neutralizes the energetic materials and precludes a detonation. The proposed approach uses organic amines, metal alkyls or amine-metal alkyl adducts to neutralize explosives. These have been shown to react hypergolically with Trinitrotoluene (TNT), Composition B, and RDX.

The chemistry related to the interaction of organic amines and metal alkyls with explosives is poorly understood and one objective of this program is to further elucidate the reaction mechanisms. Two approaches are being used for the pre-treatment of explosives: (1) relatively low temperature, controlled exothermic reactions in a liquid-phase environment, and (2) solid-state, controlled hypergolic reactions. Overall these approaches have great potential in the pre-treatment of explosives to produce a non-detonable product for reuse or final treatment in a steam reforming reactor.

The project will focus on the identification of the reaction products, their toxicity and potential reuse. Thin layer chromatography, high pressure liquid chromatography, infrared, nuclear magnetic resonance, mass spectroscopy and if necessary, preparative chromatographic methods will be employed. The products will be purified to facilitate their identification, and reactions with simpler amines such as cyclohexylamine and ethylenediamine will also be conducted to eliminate the potential for polymerization which complicates product identification.

**BENEFITS:** This project will provide DoD and DOE with an alternative method for safe and effective disposal of energetic materials. These new methods will be based on chemical breakdown of the energetic materials without detonation and are expected to exhibit high throughput, cost effectiveness, and possibilities for reuse/reapplication of the byproducts.

**ACCOMPLISHMENTS:** Organic amines were found to react with TNT, RDX and Composition B at low temperatures leading to a safe breakdown of the explosive material without detonation. Differential scanning calorimetry and adiabatic calorimetry were used to confirm these finding. The reaction of the explosive materials with the amines was associated with evolution of gaseous products. The gases were collected and analyzed by gas chromatography and infrared analyses and found to consist of nitrous oxide, nitrogen, water and carbon dioxide. The liquid byproducts were found to be effective curing agents for conventional epoxy resins. Polymers produced by this methods were found to be safe as evident by thermal analysis, detonation, and burn tests. None of the epoxy samples made with RDX/curing agent byproducts could be exploded or detonated. Mechanical properties of these polymers were measured and found to be comparable to control samples of epoxy formed from conventional resins and curing agents. The glass transition temperatures were also similar. Preliminary toxicology testing of the final epoxy made from the TNT/RDX/amine curing agent indicates that it is non-toxic.

**TRANSITION:** The technology developed under this project will be made available to users within DoD and DOE, including partners for prior collaborative efforts. Conventional chemical processing equipment is adequate for full scale implementation of this technology.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Optimization of an Innovative Biofiltration System as a VOC Control Technology for Aircraft Painting Facilities; CP-1104

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Kerry Kinney; University of Texas – Austin, TX

**FY 2000 FUNDS:** $135K

**DESCRIPTION:** Until alternative coating materials and depainting operations become available, treatment of fugitive volatile organic compound (VOC) contaminant releases during application or removal of coatings is necessary to maintain compliance with the Clean Air Act Amendments of 1990. Currently available VOC emission control technologies are costly at the high volumetric flow rates and low contaminant concentrations associated with the ventilation of aircraft hangars.

This project will develop an innovative, high flow-rate biofiltration method for treating VOC-laden air emissions. Biofiltration of painting off-gas streams currently is limited, not because of insurmountable technical problems but simply because current systems have not been designed to handle the operating conditions typical at these facilities. Innovative design features and biofilter configurations are being investigated, tested, and applied to an actual Air Force paint spray booth.

The following innovative design features are being investigated for their ability to improve biofilter performance for paint spray booth applications: (1) a recirculating inoculation method to shorten the bioreactor start-up period; (2) directionally-switching operation to improve biomass distribution and prevent clogging; (3) slip-stream feed to maintain high biomass activities during paint spray booth shutdown periods; and (4) an aerosol nutrient delivery system to efficiently deliver nutrients and moisture to the biofilm. Since bioreactor performance is strongly influenced by the contaminants being treated, the effectiveness of each design modification will be determined under single (e.g., ethyl acetate) as well as multiple [e.g. methyl ethyl ketone (MEK), methyl isobutyl ketone (MIBK), toluene] contaminant conditions representative of paint spray emissions. Other risks are whether stable and effective, long-term operation can be achieved while operating in a directionally-switching mode and using an aerosol nutrient/moisture delivery system.

**BENEFITS:** The project will provide a stable biofiltration system for paint spray booth applications that operate intermittently and emit varying quantities of VOCs. Typical biofilter problems such as long acclimation times, slow response to load changes, and biomass clogging will be overcome. The innovative biofiltration process developed by this project will, therefore, be suitable for venting of aircraft hangars during application or removal of coatings. It has the added advantages of operating at ambient temperatures and minimizing the generation of secondary wastes.

**ACCOMPLISHMENTS:** An experimental plan, test system, and experimental protocols for the project were developed and start-up experiments have been completed. The research team has constructed two stainless-steel laboratory-scale bioreactors. The analytical methods that will be used have been developed and tested, including: GC/FID for gas-phase volatile organic compounds, pH of the biofilter leachate, biofilm moisture and nitrogen content, total organic carbon, cell protein levels, total inorganic carbon, infrared CO2 analyses, and microbial plate counts. The research team also has developed and successfully used a new iodonitrotetrazolium chloride (INT) redox method for assessing biomass activity in the biofilter. Both bioreactors were initially inoculated by recirculating a liquid microbial solution throughout the packing material for a period of four to six hours prior to start up. Results from these tests indicate that the bioreactor acclimation period is very sensitive to the amount of nitrogen initially available in the system and the initial VOC contaminant feed supply. It appears that presoaking the packing media in a nitrogen rich solution prior to start up is essential to shortening the acclimation period and that unsteady inlet contaminant feed conditions detrimentally affect biofilm development. Other accomplishments include the development of

microbial cultures capable of degrading the major contaminants found in paint spray emissions. To this end, the PI's research team has isolated and developed microbial cultures that degrade toluene, ethyl acetate and MEK.

**TRANSITION:** The primary users of the biofiltration technology will be DoD paint spray booth facilities; however, the technology also will be widely applicable to the private sector. Research results will be published in forums that reach a large audience of professionals in air pollution control including the Annual Meeting of Air and Waste Management Association. A web site also will be dedicated to the proposed research and will include brief statements related to research objectives and interim results.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Membrane-Mediated Extraction and Biotreatment of VOCs; CP-1105

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Norman Kaplan; National Risk Management Research Lab – Research Triangle Park, NC

**FY 1999 COMPLETED PROJECT**

**OBJECTIVE:** Until alternative coating materials and depainting operations become available, treatment of fugitive volatile organic compound (VOC) contaminant releases during application or removal of DoD aircraft coatings is necessary to maintain compliance with the Clean Air Act Amendments of 1990. Currently available VOC emissions control technologies are costly at the high volumetric flow rates and low contaminant concentrations associated with ventilation of paint spray booths.

In conjunction with the partitioned recirculation flow reduction technique, this project developed a novel Membrane BioTreatment (MBT) system, which combined a first-stage microporous, polypropylene, hollow-fiber membranes unit to extract and concentrate VOC contaminants into a low-volatility organic stripping fluid, with a similar second-stage membrane unit in which the VOCs are extracted into a nutrient medium for biotreatment. VOC contaminants are completely metabolized by the microorganisms. Independent operation and optimization of each stage of the process will accommodate intermittent painting operations and reduce equipment size.

**BENEFITS:** This proposed treatment air emissions system will minimize the volumetric flow of contaminated air to be treated, concentrate the VOCs to reduce the size and cost of control equipment, and then completely destroy the VOCs without producing a secondary waste stream. These advantages make this VOC treatment a viable option over a broad range of spray booth sizes.

**ACCOMPLISHMENTS:** The inhibition of cell growth by methyl ethyl ketone (MEK) was investigated in a series of shake flask experiments for the MEK-degrader and the m-xylene degrader. Results for the MEK degrader showed that at an MEK concentration of 1000 ppm, an inhibited growth rate was achieved as compared to growth rates found for lower MEK concentrations. For the m-xylene degrader, an MEK concentration of 250 ppm resulted in inhibited growth. These results are useful in designing a biofilm reactor unit capable of maintaining long-term operational stability in an integrated MBT system.

Laboratory efforts concentrated on measuring mass transfer rates of VOCs from air to octanol, and on developing a coating procedure to coat polypropylene hollow fiber membrane modules with a thin polyalkyl sulfone (PAS) coating. Two Celgard Liqui-Cel modules containing fibers coated on the inside with PAS (a 16 carbon alkyl sulfone) were examined with both m-xylene and MEK as the single VOC present in an air stream feed. Fibers in the first module had a PAS coating of approximately 15-20 microns in thickness (as determined from scanning electron miscroscope (SEM) analysis of sections of fiber) and gave mass transfer results similar to those previously obtained with Liqui-Cel modules containing perfluoro dimethyl dioxol PDD coated fibers. Experiments were conducted to relate time of circulation of a PAS solution in toluene through a Celgard membrane module to the thickness and completeness of the PAS coating. Applied Membrane Technology, Inc. (AMT) was identified as a new potential membrane supplier. If the AMT module testing is successful, development of a PAS coating technique will be discontinued.

**TRANSITION:** If it is determined that the technology is economically feasible, the Air Force will identify DoD sites that are potentially well-suited to adopt this technology. The sites may include both aircraft and ground equipment painting facilities. Simultaneously, the Environmental Protection Agency (EPA) will develop a plan to transfer the technology to the installations identified. The sites will be provided with a jointly developed technology package. The intent is to select a full-scale demonstration site and propose a follow-on project. The technology transfer plan will include developing printed materials for direct mailing, papers, and presentations for symposia.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Characterization of Particulate Emission: Size Characterization and Chemical Speciation; CP-1106

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Adel Sarofim; University of Utah – Salt Lake City, UT

**FY 2000 FUNDS:** $989K

**DESCRIPTION:** The objectives of this project are to develop advanced methods for the measurement of the size distribution and composition of particulate matter (PM) emitted from mobile and stationary sources and provide the Department of Defense (DoD) with the tools needed to characterize and control the emissions from DoD facilities. The feasibility of using advanced analytical measurements to characterize the chemical composition and size of particulate emissions from a diverse range of sources operated by the DoD will be determined. The data obtained during the evaluation of the instruments will provide a measure of the relative importance of different DoD sources and will be useful for guiding strategies for controlling the emissions from DoD facilities. The cost effectiveness of different measurement methods will be assessed and recommendations made for the best protocols for measurement of fine particle emissions.

Two innovative techniques for rapid measurement of fine particles will be used in combination with a dilution sampler. The first is an aerosol time of flight mass spectrometer (ATOFMS) that measures the size and composition of individual articles. The second is a photoelectric aerosol sampler (PAS) which, in combination with a photoacoustic elemental detector (PED) for carbon, provides rapid measurement of the polycyclic aromatic hydrocarbon (PAH)-laden carbonaceous particles which dominate the emissions from combustion sources. The approach is to apply these devices in parallel with more conventional measurement techniques to establish their validity for characterizing the particle emissions from DoD sources. Multiorifice impactors (MOI) combined with chemical analysis will be used to obtain chemical characterization sufficiently detailed to close material balances on the emissions. Optical particle counters (OPC) and differential mobility analyzers (DMA) will be used to obtain detailed size distributions in order to calibrate the ATOFMS and PAS.

The first task will be to calibrate these methods in the laboratory. This will be followed by the evaluation of the use of the techniques for the measurement of emissions of aircraft engines and aircraft ground equipment at Hill Air Force Base and at the North Island Naval Air Depot. The techniques will be used finally for the characterization of open sources such as munitions disposal and dust from bombing ranges. The second task will be to enhance the measurement capabilities and compare them with other techniques. For example, the ATOFMS is now capable of determining particle sizes to 0.1 micron. The capability of obtaining smaller particle sizes will be investigated. The techniques will be used for the characterization of open sources such as munitions disposal and dust from bombing ranges.

**BENEFITS:** The project will provide DoD with rapid measurement procedures for organic and inorganic emissions at greatly reduced cost per analysis, as well as detailed chemical compositions of major source categories by size. Assessments will be provided of the relative cost of alternative measurement strategies, ease of use, potential for use for feedback control, reliability, and speed.

**ACCOMPLISHMENTS:** The value of the ATOFMS for providing diagnostics on diesel operations has been demonstrated. The ATOFMS has provided important information on the different classes of compounds emitted by diesel and spark ignition engines. Size distributions and chemical compositions have been obtained on diesel emissions. The PAS has shown potential to obtain engine emissions under operating conditions from off-runway measurements. Size distributions of particles have been obtained for different dilution systems and shown to be unaffected by the dilution process. PAH distribution between vapor, particles, and downstream of a filter have been determined. Additional funding was received from the

University of Utah to purchase a scanning mobility particle sizer (SMPS) which will enable measurements of particle size under varying sampling conditions.

**TRANSITION:** At the end of the source test program, the techniques used in the advanced source test system will be evaluated in terms of ease of use, time of sampling to obtain data, time to analyze data, and capital and operating costs. Negotiations are in progress to produce a commercial version of the ATOFMS. The current project will have developed the calibrations necessary for producing quantitative emission measurements on DoD sources as well as provided a measure of the cost effectiveness of using this technology. During the course of the project, personnel from Hill Air Force Base and the Air Force Research Laboratory will evaluate the ease of transfer of the instruments to the field.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Electrochemical Advanced Oxidation Process for Shipboard Final Purification of Filtered Black Water, Gray Water, and Bilge Water; CP-1107

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Oleh Weres; Sonoma Research Company – Napa, CA

**FY 2000 FUNDS:** $145K

**DESCRIPTION:** The overall objective of this project is to advance development of an electrochemical Advanced Oxidation Process (AOP) which will be used as a final polishing step following membrane filtration of shipboard wastewater. To comply with International Maritime Organizations Marine Pollution Convention (MARPOL) Annex V and other environmental regulations, U.S. Navy vessels require compact, energy efficient water purification technology which will allow most of the wastewaters produced on board (bilge, gray, black, etc.) to be discharged overboard following purification. Membrane filtration does not achieve the degree of purification required, and a final "polishing" process is needed prior to discharge overboard. The specific objectives of this project include producing AOP electrodes with improved service life and improved performance at low substrate concentrations, developing methods for reprocessing the electrodes, and identifying optimal operating conditions for the AOP.

Existing equipment for producing small test electrodes in the laboratory will be upgraded. An apparatus permitting long-term testing of the electrodes will be developed, and a correlation of service life vs. current density will be determined. Tests will be developed to evaluate the kinetics of different oxidation mechanisms for several substrates. X-ray diffraction, scanning electron microscopy, and specialized surface analyses will be used to characterize the crystal structure, surface morphology, and surface composition of the electrodes. Fiber made of the alloy Ti-6Al-4V (aerospace titanium) will be procured and evaluated for service as an electrode substrate. This alloy is expected to decrease the brittleness of the porous anodes produced, and thereby allow reprocessing of used-up electrodes at a fraction of replacement cost.

**BENEFITS:** Once the practical feasibility of this technology has been demonstrated, the U.S. Navy will be able to decide which combination of shipboard wastewater treatment technologies to plan for. In combination with improved membrane filtration technology, electrochemical AOP will allow existing ships to be retrofitted for compliance with MARPOL Annex V and other regulations. Estimated cost savings over 20 years are $1.49 billion (estimate of cost to off-load untreated wastewaters). Electrochemical AOP will find broad military and industrial applications, wherever moderate concentrations of contaminants need to be removed from water at moderate cost.

**ACCOMPLISHMENTS:** Two small baking chambers have been constructed, allowing complex electrode production procedures to be simulated and perfected in the laboratory. The first long-term test of electrode life has been completed. Kinetic data has been collected for several test substrates that react with hydroxyl by different reaction mechanisms, and the necessary analytical methods have been demonstrated.

A series of Ti-fiber samples representing different stages of the electrode coating process have been provided to a specialized outside laboratory for X-ray diffraction and surface analytical studies. These data revealed that the precoating process affects different fibers differently. The electronics needed for improved measurements of the electrical properties of the oxide coat have been assembled and are now operational. A device for measuring brittleness of the coated fibers by repeated bending until they fail has been built and is in use. A coating procedure has been successfully developed that gives good current yield, and at this time the attainable values of current yield are no longer limited by the quality of the oxide coat.

**TRANSITION:** Interested potential users have been identified, including: the Naval Facilities Engineering Center, the Carderock Naval Surface Warfare Center, Eaton Corporation, and Showa Engineering Co. of Tokyo, Japan. *Chemical Engineering* magazine twice described this technology, eliciting 130 requests for information. The prototype water treatment unit will very likely be carried forward to eventual commercialization.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Novel Nonporous Fouling-Resistant Composite Nanofiltration Membranes and Membrane Separation Systems for Wastewater Treatment; CP-1108

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Benny Freeman; North Carolina State University – Raleigh, NC

**FY 2000 FUNDS:** $401K

**DESCRIPTION:** Fouling associated with currently available membranes is the principal problem inhibiting widespread adoption of nanofiltration/ultrafiltration to treat shipboard wastewater to allow the Navy to meet current future overboard discharge limits. All current nanofiltration/ultrafiltration membranes are finely porous and are subject to surface or internal fouling by particulates, resulting in a dramatic decline in the water flux. The objective of this project is to develop a shipboard wastewater treatment system based on a novel type of fouling-resistant, composite-membrane module. The composite membrane will consist of an ultrathin (0.2-0.5 micrometer), nonporous, highly water-permeable, rubbery, block copolymer layer coated on to a conventional, microporous ultrafiltration or nanofiltration membrane for support. This coating layer provides fouling resistance without significantly reducing the water flux.

Three candidate materials have been developed under earlier Office of Naval Research grants. In this project, development of these membranes will be completed and a systematic series of new materials will be synthesized and characterized. The properties of these new heterophase block copolymer membrane materials will be tailored to provide better fouling resistance than conventional membranes while maintaining or improving the flux/selectivity combinations relative to currently available materials. These materials will be based on aromatic polyamide hard blocks with either hydrophilic ether groups as the soft, water-permeable block or water-soluble aromatic polyamides as the hydrophilic blocks. This research program will characterize the physical, chemical, and morphological structure of these materials as well as their water permeation, rejection, and fouling properties to develop systematic structure/property relations to guide the preparation of a new generation of advanced high performance materials for shipboard wastewater treatment. The best membrane materials will be selected for scale-up, first to bench-scale and then to industrial-scale membrane modules for evaluation in a pilot-scale system.

**BENEFITS:** Novel, low-fouling membranes for graywater and bilgewater treatment would offer longer service life and less frequent cleaning. When housed in high performance modules, these would provide a compact, reliable, economical shipboard wastewater treatment facility to enable the Navy to meet current and anticipated wastewater purification targets. This technology will be widely applicable to Navy and civilian ships and to onshore treatment of highly fouling waters.

**ACCOMPLISHMENTS:** Model compound studies have been completed and polymer precursors were prepared. The first generation of poly(ethylene oxide)-b-poly(p-benzamide) has been synthesized and two polymer samples have been identified. Films for characterization have been prepared.

**TRANSITION:** Collaboration will occur with Hydranautics Inc., San Diego, California in the module preparation work in the final phase of the project. Hydranautics is a major producer of membrane water treatment modules in the U.S. and would be a logical commercialization partner to introduce this technology to the water treatment market.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Development of a Catalyzed Ceramic Filter for Combined $PM_{2.5}$ Removal and VOC and CO Oxidation; CP-1120

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Bruce Bishop; CeraMem Corporation – Waltham, MA

**FY 2000 FUNDS:** $350K

**DESCRIPTION:** The project's objective is to develop high performance filters applicable to the treatment of a number of Department of Defense (DoD) combustion gas streams. The filters will be highly compact, ceramic-membrane-coated, silicon carbide (SiC) monolith filters, which can be additionally coated with non-selective catalysts to achieve simultaneous removal of particulate matter while oxidizing vapor-phase volatile organic compounds (VOC) and carbon monoxide (CO). The oxidation catalysts can also result in "passive" regeneration of soot to allow extended continuous operation.

The project will be carried out in three phases to develop high performance filters to control pollutant emissions from combustion gas sources: (1) Development and characterization of SiC monolith filters which will be operated in various modes, either for high-efficiency full-particulate-retention, passive catalytic regeneration or backpulse regeneration; (2) Scale-up of filter construction, catalyst impregnation methods, and testing; and (3) Single-filter, slip-stream tests at selected DoD user sites.

Three types of filter will be tested. The first is a backpulse-regenerable, compact, ceramic filter capable of reducing particulate concentrations to $PM_{2.5}$ compliant levels. The second is similar to the first except that an oxidation catalyst will be deposited on and within the pore structure in order to simultaneously remove gaseous pollutants such as VOCs and CO. The third filter type will be similar to the first except that an oxidation catalyst for removal of organic particulate will be deposited on the surface of the membrane coating. This catalyst will passively regenerate the filter by oxidizing the filtered particulates, thereby eliminating the need for backpulsing. After the development of prototype filters, field tests will be conducted to demonstrate the efficacy of removing particulates, VOCs and CO from selected gas streams. Ceramem will provide two existing, highly instrumented, high-temperature-duty, gas filter pilot plants for these field tests.

**BENEFITS:** The DoD and Department of Energy (DOE) need new, cost-effective technologies to comply with the proposed, more stringent EPA standards for particulate matter as small as 2.5 microns ($PM_{2.5}$) for sources such as jet engine test cells (JETC), diesel engines, generators, incinerators and steam boilers. If effective, the proposed filters will bring a unique combination of particulate removal capability ($PM_{2.5}$ compliant), temperature resistance (900° C), and compactness (more than any other competitive filter) with the ability to be catalyzed for simultaneous collection and destruction of organic particulate and gaseous pollutants.

**ACCOMPLISHMENTS:** A membrane coating formulation and casting process has been developed that results in high particulate retention, on in-house tests, and meets the gas flow pressure drop criteria. Additional work is needed to make the process more robust and to make samples for testing at University of North Dakota Energy and Environmental Research Center (UNDEERC). Passively-regenerated filters are being prepared at Prototech Corporation as well as at CeraMem. Test equipment has been designed, reviewed for safety, and assembled.

CeraMem has started making some commercial contacts in the diesel after-treatment market. These contacts may be helpful in defining real after-treatment performance targets, developing field test locations for future evaluations, and commercialization of the technology.

Membrane-coated filters were treated with both commercial (Prototech Company) and CeraMem developmental soot oxidation catalysts. Testing on the uncatalyzed filter showed no oxidation of the soot (i.e., no CO generation) until about 400 degrees C with a maximum at about 600 degrees C. Filters similar to those tested for soot oxidation were tested for CO oxidation. The test results indicate that the catalyzed filters were active for CO oxidation.

**TRANSITION:** The proposed ceramic filter technology will yield a Best Available Control Technology (BACT) for specific operational niches such as confined spaces, high temperature duty, and simultaneous removal of particulates, VOCs, and CO, with the potential for additional downstream nitrogen oxide destruction. The transition plan includes licensing the technology to filter manufacturers.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Reduction of Particulate Emissions from Jet Engine Test Cells Using an Annular After-Reactor; CP-1126

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Norman L. Helgeson; Naval Facilities Engineering Service Center – Port Hueneme, CA

**FY 2000 FUNDS:** $585K

**DESCRIPTION:** This project will develop a prototype Annular After Reactor (AAR) jet-engine attachment to reduce particle emissions from jet engine test cells (JETC). The AAR, positioned in the flow path of the jet engine exhaust tube, is simply a hollow pipe which delays mixing of exhaust gases with the surrounding air stream for a sufficiently long residence time to permit incineration of the particulate matter (PM), up to 90%, with minimum pressure drop. With a slight modification, the system may also be adapted for removal of NOx, CO and unburned hydrocarbons.

The project will be carried out in four phases: (1) analytical and computer studies to refine the basic AAR fluid dynamics model and establish design criteria for field tests; (2) intermediate-scale field testing to complete the AAR design; (3) full-scale AAR system fabrication and field testing at a California Naval Air Station; and (4) data reduction and analysis to provide the recommended AAR system for PM reduction. The most challenging technical aspect of this study will be the efficient and rapid mixing, and combustion, of the injected natural gas within the AAR to achieve a proper temperature profile. Excessive pressure drops are expected to be eliminated by using a jet exhaust diffuser on the inlet to the AAR. The challenges of non-steady operating conditions will be addressed by using a feed-forward control system to make required AAR adjustments in concert with programmed changes in engine operating conditions. By maintaining the temperature of the exhaust gases within the AAR at 2000F, it is believed the generation of nitrogen oxides within the AAR will be insignificant.

**BENEFITS:** The DoD and DOE need new, cost-effective technologies to comply with the proposed, more stringent EPA National Ambient Air Quality Standards (NAAQS) for particulate matter below 2.5 microns ($PM_{2.5}$) for sources such as JETCs, and future National Emission Standards for Hazardous Air Pollutants (NESHAP) specific to JETC emissions. If demonstrated to be effective, the AAR is a minimum-capital-cost, minimum-operating cost approach for reducing PM emissions from JETCs.

**ACCOMPLISHMENTS:** Initial experimental velocity and temperature profiles using sub-scale NFESC JETC were completed as well as the validation of sub-scale computer models with JETC/AAR fluid flow test temperature profiles. A major effort has been underway to assemble a sub-scale test system of the AAR. In addition to the design, fabrication, and installation of the sub-scale test hardware, efforts have focused on the supporting fluid dynamic and thermal analysis of the AAR and how these results can be used and related on the sub-scale, intermediate-scale, and full-scale systems. A patent application has been filed covering several aspects of the AAR. Several meetings took place to review and examine the findings of other SERDP projects and their relationship to the objective of this project. The"trapped vortex combustor" technology that Wright-Patterson Air Force Base is developing to accomplish step change improvements in gas turbine efficiency, reduced emissions, and increased engine power, could have application in development testing of the AAR. This technology will be considered further as design and analysis of the AAR progresses.

**TRANSITION:** The Army, Navy and Air Force have each expressed an interest in application of this proposed technology. In addition to JETCs, this technology has the potential to transition to other stationary and mobile sources of combustion emissions.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Thermal Actively Controlled Sludge Treatment; CP-1132

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Klaus C. Schadow; Naval Air Warfare Center – China Lake, CA

**FY 2000 FUNDS:** $970K

**DESCRIPTION:** This project proposes a system that addresses the sludge disposal problem onboard ships by using a unique, highly compact and high performance combustion process. The project's objective is to develop a two-stage incineration process comprising: (1) a primary vortex containment combustion (VCC) process, which also separates and retains particulates; (2) a self-propagating, high-temperature synthesis (SHS) thermal processing and encapsulation process for treatment of resultant ash; and (3) an actively controlled and monitored after-burner (AB) process for emissions reduction. The process can be automated and integrated into a comprehensive, continuously operated, oily water treatment system.

The technical approach builds on the compact, closed-loop controlled waste incinerator for blackwater successfully developed in previous SERDP projects CP-034 and CP-887. The project consists of six developmental phases: (1) fundamental laboratory-scale studies (injection, swirl design, flame stability, laser diagnostics, modeling, ash treatment) on surrogate sludge waste mixtures; (2) VCC and AB integration schemes; (3) conceptual design; (4) scale-up and testing of practical embodiments under full-scale conditions; (5) integration of monitoring and automatic active control schemes; and (6) testing requirements definition for future transition to a demonstration/ validation program.

**BENEFITS:** The Department of Defense (DoD) currently makes wide use of oil/water separators (OWS) to remove oil from a variety of aqueous waste streams prior to discharge. On-site or shipboard methods to treat or reduce the volume of accumulated sludges generated by these OWSs are required to eliminate sludge transportation costs for offsite disposal, to reduce downtime for maintenance, and to increase separator efficiency. The Navy is spending about $24M per year to treat 1 billion gallons of bilge oil which includes its storage, off-loading, on-shore treatment, transportation, and off-site disposal. This technology could significantly reduce costs with on-site disposal, either on shore facilities or, for larger vessels, on-board ship. Other advantages of on-site disposal include the increasing costs of off-site disposal, reducing assumed liability of third party disposal, eliminating waste handling and transportation, and avoiding costs for improper field disposal.

**ACCOMPLISHMENTS:** In FY99, the integration tests with Golar 500 and the actively controlled afterburner of the CP-887 project on Compact Waste Incineration were successfully completed. The British Thermal Unit (BTU) waste through-put of the off-the-shelf Golar was increased by a factor of three and the carbon monoxide (CO) emission was reduced by a factor of nine. This understanding of this technology was instrumental in the design and fabrication of the VCC/AB in the present project.

When the AB was integrated with the VCC, tests showed that the VCC swirl does not adversely effect the AB performance; however the swirl generates its own self driven oscillations with varying frequencies, which interfere with the active control of the AB. New approaches for active control will have to be developed.

The VCC Laboratory Combustor was designed, fabricated, and assembled. Gaseous fuel combustion characteristics (flammability limits, stability, flame location) have been established for varying operational conditions. Cold flow experiments with particles were started. The diode laser system that will be used to follow the particle history from injection to suspension and ejection from the VCC has been set-up. The set-up of an existing full-scale isothermal VCC model was completed. Studies of injection techniques for auxiliary fuel and simulated sludges were started to achieve optimum droplet and particle suspension. The design of VCC Test Unit has been completed with a flow rate of 50 gph (sludge plus auxiliary fuel).

**TRANSITION:** The user community will be involved throughout the development of the proposed work. There have been discussions with Navy organizations, and the Army and Air Force have also expressed interest in the new sludge treatment system for potential application to a Deployable Waste Disposal System.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Purification of Oily Wastewaters by a One-Step Advanced Biodegradation Process that Produces No Secondary Wastestreams; CP-1136

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Harris Gold; Foster-Miller, Inc. – Waltham, MA

**FY 2000 FUNDS:** $443K

**DESCRIPTION:** The overall objective of this project is to demonstrate a low maintenance biological process for onboard treatment of bilge water to meet the 15 ppm International Maritime Organizations Marine Pollution Convention (MARPOL) oil discharge provision and in which the oil contaminants are completely degraded to carbon dioxide and water.

A new technique, called forced molecular evolution, will be used to cultivate enhanced optimized microorganisms needed for a robust, high throughput biological process with performance, size and maintenance characteristics suitable for shipboard deployment. The method has two steps: (1) a whole-cell, mutagenic selection technique to rapidly cultivate broadly non-specific bacterial strains tailored to the pressures imposed by the wastewater, and (2) a genetic enhancement technique to further optimize and tailor the degradation capability of the selected bacterial strains.

The other major part of the program involves the development of a new bioreactor to treat the bilge water to meet the MARPOL discharge requirements. The approach that will be taken is to try to retrofit existing oil/water separators (OWS) to achieve the high oxygen rates and reduce the costs of implementation.

**BENEFIT:** The immediate environmental benefit derived from this program is the development of a new technology platform that is applicable to a widely diverse set of Department of Defense (DoD) and industrially related environmental problems. The methods and designs that will be developed are immediately applicable to current DoD needs. At the conclusion of this project, microbial consortia will be available for the treatment of bilge water and for wash rack and wash down waters from DoD maintenance facilities. In addition, a small pilot plant bioreactor system will be available to evaluate various DoD-generated wastewaters. The potential savings to the DoD for the long term would be about $25 million annually with about 10 percent related to a reduction in maintenance costs and 90 percent related to a reduction in the costs of disposing of the separated oil. It is also expected that the design of the new bioreactors would be based on retrofitting existing oil/water separators (OWS) to achieve high oxygen demand rates and reduce the cost of implementation; this latter cost reduction has not been estimated.

**ACCOMPLISHMENTS:** The Naval Research Laboratory (NRL) plated the Sequential Batch Reactors (SBR) biomass sample on Luria-Bertain agar (105 cfu/mL). Selected colonies are being identified by the Biolog(TM) ID system; 16s rRNA sequencing may be used on isolated colonies. Thus far, 10 clones have been sequenced from the SBR biomass.

At Polytechnic University, the New Brunswick Fermentor, a Perkin Elmer GC, and other equipment necessary to carry out the test program have been set up and checked out. Inocula from Craney Island were received and used to initiate enrichment cultures to obtain organisms capable of degrading organic material from bilge water. Cultures currently are under study to determine their ability to degrade various target contaminants under fixed conditions. Experimental design strategies have been used to select experiments to study multiple variables with a limited set of experiments.

At Tufts University, genetic enhancement data bases have been assembled on all of the well-characterized catabolic plasmids that would likely be involved in the degradation pathways for the organic components of oil. Primers and probes have been designed against each of the genes in these pathways and the

information cataloged. Suitable bacterial strains and catabolic plasmids have been obtained to conduct baseline studies to address two issues of relevance to the study: (a) natural rates of genetic exchange and (b) rates of molecular evolution in well-defined systems, to provide context for the complex soil degradation system.

**TRANSITION:** Foster-Miller has initiated a teaming agreement with Enviroenergy Systems International, Inc. (ESII) of McLean, VA of the development and commercialization of the kinetically-enhanced optimized microorganisms for the treatment of oily wastewaters generated by DoD operations. ESII will manufacture and market both the microorganisms in a dry powdered form and the bioreactors. Upon successful completion of the SERDP effort, sufficient information will be available to initiate scale up and field testing of the prototype products(s) possibly through ESTCP or other demonstration funding process.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Distribution and Fate of Energetics on DoD Test and Training Ranges; CP-1155

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Judith Pennington; U.S. Army Corps of Engineers Engineer Research and Development Center, Environmental Laboratory – Vicksburg, MS

**FY 2000 FUNDS:** $361K

**DESCRIPTION:** The primary objective of this project is to provide the Department of Defense (DoD) with techniques to assess the potential for groundwater contamination from residues of high explosives (TNT, PETN, RDX, and HMX) at testing and training ranges. Results of the project will facilitate informed management decision making, minimize environmental impacts of testing and training, and contribute to continued operation of ranges.

The initial tasks will be to identify the energetics composition of formerly and presently used munitions and assess the kinds and numbers of unexploded ordnance (UXO) that can be expected at various types of ranges. The research team currently possess a listing of UXO recovered from two major firing ranges and is in the process of augmenting this information with data from other sites. Procedures for determining the concentration and distribution of post blast residues will be based upon methods developed from previous sampling of ranges. Methods developed in the Defense Advanced Research Projects Agency (DARPA)-sponsored Dog's Nose project on chemical detection of landmines will be used to characterize low levels of post blast residues.

Once the composition of post blast residues including environmental transformation products of explosives is evaluated, which may be produced by both primary and secondary charges in munitions, environmental transport parameters will be developed and the distribution and concentration of the residues at ranges will be determined.

Transport parameter studies will concentrate on main-charge explosives, their transformation products, and explosives residues for which fate and transport process descriptors are nonexistent. On-going research at testing and firing ranges will facilitate identification of research sites and access to records and ranges. Firing histories, fate and transport characteristics of explosives residues, and the distribution and concentration of the residues will be used as input for simulation models to evaluate impacts to soil and groundwater. Because of the extreme heterogeneity expected, special attention will be given to methods for collecting representative samples on ranges, including guidance concerning experimental design, and statistical techniques.

**BENEFIT:** The results of this project will contribute to an understanding of key processes affecting the potential for explosives residues to impact the environment. Project results will document activities at test and training ranges that have the potential to cause groundwater contamination by residues of high explosives. Immediate benefits will include guidance for characterizing contamination efficiently and cost-effectively, tools for anticipating the potential for environmental impacts and for demonstrating responsible management of facilities to sustain their use for testing and training. These methods could result in substantial cost saving for site characterization, and sustained use.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** Programs in place at all of the performing organizations will facilitate future widespread application of the procedures to determine the distribution and fate of energetics on DoD test and training ranges. Researchers at the U.S. Army Corps of Engineers Engineer Research and Development Centers' (ERDC) Environmental Laboratory and Cold Regions Research and Engineering Laboratory (CRREL), as

well as Sandia National Laboratory (SNL) are actively involved in developing procedures to assess the fate and transport of explosives from UXO. The research team has been advising the National Guard on the complex problems with explosives at the Massachusetts Military Reservation. A demonstration program under the Environmental Security Technology Certification Program (ESTCP) can validate guidance with on-site evaluation and modeling that are developed in the proposed project with which ERDC and SNL have prior experience.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Determining the Fate and Ecological Effects of Copper and Zinc Loading in Estuarine Environments: A Multi-Disciplinary Program; CP-1156

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Alberto Zirino; Space and Naval Warfare Systems Command – San Diego, CA

**FY 2000 FUNDS:** $310K

**DESCRIPTION:** The objective of this work will be to produce a method for estimating the impact of copper and zinc loading in estuarine environments, in specific mixing zones, and throughout entire aquatic basins. Copper and zinc species will be incorporated in a hydrodynamic (physical) estuarine model that simulates the principal estuarine topography, tidally-driven currents, meteorology, and bottom characteristics. The model is used to compute water residence times in the estuary, the key physico-chemical variable against which all other rate-dependant processes are evaluated. Steady-state concentrations of metal species, including the steady-state concentrations of the "free" hydrated metal ion are computed from the hydrodynamic model, using known or experimentally measured input and sedimentation data for the estuary. The computed steady-state concentrations of copper and zinc species are then compared to the experimental data and the model is fine-tuned by adjusting interspecies reaction (rate) constants, until the model is optimized to reproduce the copper and zinc dynamics. The environmental impact of the steady-state concentrations of the toxic copper and zinc species will be evaluated in laboratory tests, as well as through field observations.

The principal investigators from this project will be collaborating with the other two SERDP projects on copper and zinc in estuarine system (CP-1157 and CP-1158) and with other Navy projects working in this subject area in an effort to foster close cooperation and exchange of information. In addition the three SERDP projects will develop unified sampling and analysis techniques.

**BENEFIT:** This program will be provide benefit to the Department of Defense (DoD) and the broader environmental compliance world through several pathways: (1) the developed methods and data will be important to the DoD Uniform National Discharge Standards Program (UNDS); and (2) the information from this project will be transitioned to DoD environmental managers dealing with facilities and dredging compliance issues. The science resulting from the project should provide a basis for DoD to work with Environmental Protection Agency (EPA) in developing water quality criteria which takes into account the importance of metal species and complexation on toxicity. Finally the scientific approach developed under this program can be used as a model for supporting development of reasonable criteria and standards for other metals and contaminants.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** The products of this project will be transitionable to Environmental Security Technology Certification Program with proposed joint funding from the Navy's 6.4 Shoreside Pollution Abatement Program. Technology transfer will be through peer-reviewed journals, technical reports and symposia. A workshop will be held during the first year, co-sponsored by the Navy Applied Research 6.2 Program to address copper and zinc technical and regulatory issues.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Speciation, Fluxes, and Cycling of Dissolved Copper and Zinc in Estuaries: The Roles of Sediment Exchange and Photochemical Effects; CP-1157

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Stephen Skrabal; University of North Carolina – Wilmington, NC

**FY 2000 FUNDS:** $171K

**DESCRIPTION:** The goals of this study are to: (1) quantitatively determine water column concentrations and benthic fluxes of total dissolved (TD) copper (Cu) and zinc (Zn), dissolved Cu- and Zn-complexing ligands, and ancillary parameters at two sites in the Cape Fear Estuary, NC; (2) determine changes in cycling, fate, and organic speciation of dissolved Cu and Zn that may occur during resuspension events, focusing on the role of photochemical reactions; and (3) examine the effects of a large-scale dredging project on the speciation, fate, and cycling of Cu and Zn in estuarine waters and sediments.

Sediment and water sampling will be conducted primarily at two sites, each of which are subject to shipping and berthing activities representative of Department of Defense (DoD) harbor facilities. Water column samples at the surface (~2 m depth) and near the bottom (1-2 m above the sediment surface) will be collected and filtered in the field using a clean pumping and filtration system. Benthic fluxes of TD Cu and Zn, dissolved Cu- and Zn-complexing ligands, and dissolved organic carbon (DOC) will be measured using a core incubation technique. Controlled photolysis experiments will be performed on sediment suspensions.

The principal investigators from this project will be collaborating with the other two SERDP projects on copper and zinc in estuarine system (CP-1156 and CP-1158) and with other Navy projects working in this subject area in an effort to foster close cooperation and exchange of information. In addition the three SERDP projects will develop unified sampling and analysis techniques.

**BENEFIT:** The proposed project will provide a large number of direct measurements of benthic fluxes of Cu and Zn and their complexing ligands, and quantify the contribution of benthic fluxes to the amount of complexed Cu and Zn and of Cu- and Zn-complexing ligands in harbor waters. This project uniquely proposes an examination of photochemical effects on Cu and Zn speciation in estuaries and harbors. The results of this project can be used to develop scientifically-based standards for Cu and Zn in the aquatic environment.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** The data presented by this project will provide information on the potential amelioration of Cu and Zn by dissolved organic ligands in harbors and estuaries. This data can be used by DoD to evaluate water quality compliance criteria that are based on environmentally relevant impacts of metal discharges, and hence to ensure that economic resources devoted to environmental monitoring and compliance are most efficiently utilized.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Speciation, Sources, and Bioavailability of Copper and Zinc in DoD Impacted Harbors and Estuaries; CP-1158

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Martin Shafer; University of Wisconsin – Madison, WI

**FY 2000 FUNDS:** $361K

**DESCRIPTION:** The overall goal of this project is to advance the current understanding of the fate and impact of copper and zinc in harbors and estuaries. Specifically, to develop a quantitative understanding of the speciation, bioavailability and fate of important metal species transported to and found within Department of Defense (DoD)-impacted harbors.

Specific objectives of this project are to: (1) apply and refine methods for speciation of copper (Cu) and zinc (Zn) in harbor and estuary waters; (2) assess the influences of environmental factors and processes on the speciation and fate of Cu and Zn; (3) interpret experimentally determined lability estimates of dominant metal-complexes in terms of time scales relevant to biological and physical processes in DoD impacted harbors; (4) compare modeled estimates of bioavailability of specific phases with biochemically determined exposure on experimental organisms; and (5) determine sources of Cu and Zn to harbors and estuaries using a multi-faceted approach of selective sampling, metal phase discrimination, and unique stable isotopic signatures to distinguish DoD sources of Cu and Zn from other sources to harbors and estuaries.

The intent of this project is to isolate functionally distinct metal "pools" within harbor systems and characterize the lability of Cu and Zn within these pools. The nature and sources of ligands in specific pools will be determined by chemical and biochemical means. Measurements of lability in specific pools, as defined by chemical and physical speciation techniques will be complemented and validated by bioassays at both the molecular and organism level. Stable isotopes of Cu and Zn will be explored as tracers of source and source specific bioavailability.

The principal investigators from this project will be collaborating with the other two SERDP projects on copper and zinc in estuarine system (CP-1156 and CP-1157) and with other Navy projects working in this subject area in an effort to foster close cooperation and exchange of information. In addition the three SERDP projects will develop unified sampling and analysis techniques.

**BENEFIT:** These findings will allow the development of a method for the assessment of the potential of Cu and Zn to impact biological communities. This work, therefore, will have direct bearing on the establishment of water quality criteria in these systems. This study will provide a crucial test of the applicability of stable isotopes to aid in source reconciliation and bioavailability studies. Important parameters will be established from which the precision of source assignment can be assessed. The approach of source tracing and apportionment by stable isotopic signatures should have broad applicability to both aquatic and terrestrial DoD sites and the exploratory work in this study will provide that assessment.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** The technology underpinning the method of assessing the potential of Cu and Zn to impact biological communities should be readily transferable to DoD or DoD contractors. Data developed on Cu and Zn sources to, and within, the study systems will be used to construct or refine mass balances of metal loading. When coupled with information generated from this study, on source specific metal availability, appropriate resources can be directed to controlling inputs with the greatest potential for ecosystem impact. Recommendations along these lines will be prepared for DoD, which may then use these data in future permitting applications. DoD can use information from this project to determine whether stable-isotope technology should be applied to other impacted sites.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** A Predictive Capability for the Source of Terms of Residual Energetic Materials from Burning and/or Detonation Activities; CP-1159

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. John Zhang; Aerodyne Research, Inc. – Billerica, MA

**FY 2000 FUNDS:** $283K

**DESCRIPTION:** The overall goals of this project are to: (1) understand and quantify the major chemical and physical processes, such as afterburning effects, and formation and deposition of particles; (2) develop a Source Characterization Model (SCM) for predicting accurately the source terms resulting from the burning and detonation of munitions, including both gaseous and particulate species; (3) link the SCM output to appropriate fate and transport models in air, soil, or water medium; and (4) validate the final SCM against a few typical scenarios.

This project will develop the SCM and related databases and link them to available dispersion and transport models. The input to the SCM will include munitions or energetic identity and weight, ambient site conditions, and site-specific conditions for the open burn/open detonation (OB/OD) or use of munitions. The SCM will include algorithms, supporting databases, and a graphical user interface for the prediction of chemical identities and emission factors, particle size and deposition, plume buoyancy, and plume size at final rise. The output of the SCM will be used as input conditions to existing transport and dispersion models in air, water, and the ground surface.

**BENEFIT:** The estimated benefits to the Department of Defense (DoD) are cost reduction by modeling and cost of incomplete responses to regulatory concern. The total cost of emission characterization by testing for an estimated 400 unique munitions could cost DoD from $0.5 billion to $1 billion. Assuming that only 1 in 20 munitions requires testing and the rest can be modeled, the savings from modeling could exceed $475 million. Typically an installation may spend up to $2 million monitoring groundwater and sampling soil in order to satisfy regulators and the public that munitions use or OB/OD has no impact to human health or the environment. The development of a capability incorporating testing data and the prediction of chemical species of concern is expected to reduce regulatory requirements for testing and monitoring.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** The developed modeling capability will be a public domain environmental assessment model. Upon the completion of the project, the capability will be available to USAEC. It will be reviewed for acceptance by applicable EPA offices involved in emissions modeling. Subject to EPA approval, it will be made available through the EPA regulatory support electronic bulletin board. The project results will be presented to potential users via journal articles, symposia, and technical reports. The potential users include all DoD, DOE, and EPA activities involved in OB/OD. User guides and technical description of the capability will be released by Aerodyne Research in interim and final forms during the project. The developed capability, as a readily available and off-the-shelf product, will be user-friendly and run on a PC under Microsoft Windows.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Use of a Nafion Membrane Probe for Quick, On-the-Spot Determination of Ionic Copper Contamination Levels in Natural Waters; CP-1160 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. John Foerster, U.S. Naval Research Lab – Annapolis, MD

**FY 2000 FUNDS:** $100K

**OBJECTIVE:** The objective of this project is to develop a user-friendly detection system that allows for the rapid assessment of the major ionic copper ions in the marine environment. Emphasis is on those ionic copper species [Cu(I) and Cu(II)] which may adversely affect the marine environment. The overall goal of the project is the prove the concept of an ionic copper probe that has parts per billion (ppb) detection limits, and is easily used by dockside personnel having little to no formal chemical analysis training.

The copper sensing probe uses polymer technology with an impregnated color indicator. The active component of the probe is comprised of the polymer Nafion 117. The polymer is impregnated with a copper (I) metal ion organic complexing agent, 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (Bathocuproine or BCP), and attached to a plastic panel. The panel is immersed in a known volume of water suspected to contain copper (I). After 20 minutes, the test panel is removed from the solution and the active component of the tester (Nafion film and BCP) is compared to the color panel on the tester. A relative concentration of copper (I) can be determined. BCP reacts with Cu(I) to give a very intense, visible and stable orange-complex with a unique spectroscopic signal. By adding a reducing agent, Cu(II) can be measured.

**BENEFIT:** A simple to use, inexpensive ionic copper monitoring system will aid in the implementation of the Uniform National Discharge Standards (UNDS) Act which will mandate some form of sensor/detection system that can address the role of speciation [Cu(I) and Cu(II)] marine environments.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** This project is a cooperative study between the Oceanography Department of the U.S. Naval Academy and the Environmental And Sensor Chemistry Section, Chemistry Division of the Naval Research Laboratory. UNDS has identified 25 discharges requiring Marine Pollution Control Devices (MPCD). Three of these discharges that can be monitored with the Nafion Membrane Probe are: (1) hull coating leachate; (2) seawater cooling overboard discharges; and (3) underwater ship husbandry. Possible funding to continue scale-up production of the Nafion Membrane Probe via NAVSEA is a very good possibility once the proof-of-concept has been shown. Another possible funding source/user of the probe would be various state agencies that would probably require monitoring capabilities in the marine environment in support of UNDS.

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# APPENDIX C
## Conservation Project Summaries


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| CS-1054 | Development and Demonstration of a Risk Assessment Framework for Natural Resources on Military Training and Testing Lands | C-4 |
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## PROJECT SUMMARY

**PROJECT TITLE & ID:** Threatened, Endangered, and Sensitive Resources; CS-507

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Keturah Reinbold; U.S. Army Corps of Engineers Engineer Research and Development Center, Construction Engineering Research Laboratory – Champaign, IL

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** Growing numbers of threatened, endangered, and sensitive (TES) species found on military lands increasingly result in mission constraints and impediments to land acquisition, potentially leading to reduced defense readiness; lengthy and costly litigation; and criminal and civil penalties. Major objectives of this research were to continue efforts to manage TES habitats and to mitigate the effects of military-unique impacts. Specific technical objectives were to: (1) develop regional guidelines for TES habitat/community evaluation and management; (2) evaluate approaches, methodologies, and techniques to enhance conservation of TES plant population; and (3) develop conceptual models of impacts of smokes, obscurants, and chemical stimulants on TES and make predictive assessments of effects of selected material and species.

**BENEFIT:** These efforts contribute substantively to a comprehensive, systematic, and integrated approach to TES management on military lands. Through this effort, the military has developed and demonstrated scientific and technical leadership in the management of TES, thus allowing for better integrating TES considerations with military activities while avoiding mission impacts. On-going interagency coordination will yield benefits at the national, regional, and local levels. Improved prediction of smokes and obscurants has helped the communities provide a realistic assessment of risks to threatened and endangered species.

**ACCOMPLISHMENTS:** Six technical reports highlight selected native plant communities in the southeastern U.S. that provide regional habitat for multiple TES. Another report reviews known effects of mechanized military training on these communities. Eighteen faunal species profiles were published to accompany the plant community reports. A summary document synthesizes the information and provides a habitat-based, multi-species prototype management plan for use on DoD facilities in the SE region. The prototype is designed to form the basis for management strategies developed for Endangered Species Management Plans and Integrated Natural Resource Management Plans. The project also analyzed the effects of smokes and obscurants on surrogates for endangered species, especially the red-cockaded woodpecker (RCW) in the Southeastern United States. Laboratory exposures of surrogate adults, nestlings and eggs at highest expected field concentrations of fog oil aerosol were found to have no significant effect

**TRANSITION:** Products of this research will support the Army's environmental and endangered species management strategies and aid in efficiently meeting Army TES policies and regulatory requirements. A SERDP TES web page on faunal species is available online (http:/www.wes.army.mil/el/tes). A model to predict dispersion of fog oil linked with GIS to make it specific for a particular installation location is being integrated into Land Management System (LMS). The research team will transfer research results to military trainers and land managers at HQ, Command, and installation levels. Methods, protocols, and user manuals will be distributed via training commands to installations.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Advanced Biotelemetry for Resource Management; CS-759

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. William Seegar; Army Research Laboratory – Aberdeen, MD

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** This project focused on the development and testing of 1-2 gram, radar-activated, radio tags for tracking and monitoring extremely small birds and other species. The technical objective was to develop and evaluate the potential of harmonic radar to track regional and local movements of threatened, endangered, and sensitive species for risk assessment and ecosystem management.

**BENEFIT:** Cost savings to the military will accrue in several ways. First, application of new methods and techniques will allow more effective study of special status species. Second, application of these methods and techniques will require fewer personnel than in the past. Third, fewer persons in the field for shorter periods will reduce interference with military activities. The near real-time integration of this data collection capability with both Geographic Information Systems (GIS) natural resource information and military land use activities will provide managers with a unique ability to support readiness on installations while managing for conservation and biodiversity. The use of harmonic radar tracking provides DoD and other land managers with sophisticated refinement of field ornithology at a time when there is tremendous pressure to manage and protect many small avian species.

**ACCOMPLISHMENTS:** A working benchtop prototype tag (weighing about 2 grams) was developed and assembled. The tag is activated by a pulsed radar signal and replies with a very high frequency (VHF) signal. Platform transmitter terminal (PTT) technology has been demonstrated on a wide variety of species on military lands to provide fundamental information with which to make informed policy decisions and resource management plans. PTT technology was demonstrated on: (1) white pelicans and white-faced Ibis at Naval Air Station Fallon, NV; (2) Ferruginous Hawks at Hill Air Force Base, UT; (3) wild horses and pronghorn at Dugway Proving Grounds, UT; and (4) oryx at White Sands Missile Range, NM. Scale up to field application is underway and will be completed during 2000.

**TRANSITION:** This innovative diode-based radar system fills a critical information gathering technology gap and can significantly assist in the conservation of a vast array of species presently in jeopardy. The tools developed to mitigate bird strike hazards for military aircraft at airports can also be used at commercial airports. All of the technology products from this project are being transitioned to research applications through the University of Maryland's Center for Conservation Research and Technology and other research institutions for commercialization and implementation in the private sector.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Development and Demonstration of a Risk Assessment Framework for Natural Resources on Military Training and Testing Lands; CS-1054

**PRINCIPAL INVESTIGATORS & ORGANIZATION:** Dr. Keturah Reinbold / Ms. Winifred Hodge; U.S. Army Corps of Engineers Engineer Research and Development Center, Construction Engineering Research Laboratory – Champaign, IL

**FY 2000 FUNDS:** $200K

**DESCRIPTION:** Downsizing of military installations has increased demand at remaining installations for airspace, water and land area for military testing and training. Long-term suitability of training and testing areas and compliance with environmental regulations must be maintained. The objective of this effort is to develop a structured, scientifically valid risk assessment framework that can be rapidly and inexpensively applied to assess risks of single, multiple, or cumulative impacts of military training and testing activities on natural resources. This framework will incorporate physical, chemical, and biological stressors (including noise) and their direct and indirect effects, short and long term, on natural resources. The feasibility of linking Incremental Cost Analysis with the risk assessment framework will be examined.

**BENEFIT:** This framework will support a risk-based context which will assist the Department of Defense (DoD) to better conduct training and testing activities while complying with environmental regulations, maintaining training and testing realism, and maintaining stewardship of natural resources.

**ACCOMPLISHMENTS:** The three top-priority military activities of concern for the potential to impact natural resources were identified by the User Advisory Group: (1) aircraft overflights, (2) use of ocean ranges, and (3) firing at targets. Eglin Air Force Base, Florida, was identified as the top priority installation for demonstration. A draft of the activity-specific framework for low-altitude aircraft overflights has been completed, submitted to the User Advisory Group, and altered to reflect comments by the group and other technical and military reviewers. Two papers were published in the peer-reviewed journal, Human and Ecological Risk Assessment in April 1999. One paper covers the overall framework, and the other specifically addresses the method for developing conceptual models for the framework.

**TRANSITION:** Specific DoD training or testing activities at particular facilities will be used to demonstrate risk assessment framework. An example application of the site-specific framework, applying one or more of the activity-specific frameworks, will be conducted at selected installations.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Analysis and Assessment of Military and Non-Military Impacts on Biodiversity: Framework for Environmental Management on Department of Defense (DoD) Lands Using Mojave Desert as a Regional Case Study; CS-1055

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. David Mouat; Desert Research Institute – Reno, NV

**FY 2000 FUNDS:** $300K

**DESCRIPTION:** This research aims to develop a methodology for regional management of biodiversity and related ecological, stakeholder, cultural, and environmental resource concerns. The project is expanding research and technology developed at Marine Corps Base (MCB) Camp Pendleton to address environmental problems at the regional scale in the western Mojave Desert (and will be coordinated with adjacent Department of Energy land holdings). It is analyzing the impacts of military and non-military stressors on patterns of biodiversity and related environmental resources and is assessing the impacts future land uses are likely to have on patterns of biodiversity.

Consisting of four components or phases, this project involves: (1) the development of a Quality Assurance/Quality Control plan and a peer-reviewed experimental design; (2) the initiation of a spatially-oriented data base management and decision support system; (3) the organization of a military and non-military stakeholder group to identify environmental issues and human valuations of the regional ecosystem both within and outside the military context; and (4) identification of military and non-military stressors. The basic methodology for deriving habitat information through vegetation - terrain correlation is being established.

Interaction with ongoing Legacy Program activities (for their data bases) through the U.S. Geological Survey's National Biological Resources Division and other groups is critical to this project. The analysis and assessments phase identifies habitat relationships and assesses the management strategies for the Desert Tortoise and other key species. The habitat and management strategies key species are derived and correlated to associated species. Existing land use activities and other stressors on habitat and biodiversity are being evaluated. The effects of future land use scenarios on stressors and on the likely impacts on biodiversity and related environmental resources are being modeled.

**BENEFIT:** This project provides DoD with the capability to evaluate impacts of both DoD and non-DoD stressors (such as off-road vehicle use and suburban development) on military activities. Through integrated regional ecosystem management, the military can more effectively negotiate biodiversity and other ecosystem management issues with surrounding stakeholders, ensuring minimal environmental damage while maintaining and enhancing the military mission.

**ACCOMPLISHMENTS:** Species modeling and modeling input for the generation of alternative futures continues to be developed. Population growth and movement over the Mojave landscape as a function of precipitation, road density, vegetation, soil, and elevation are recent developments of the tortoise model. A digital coverage of the various land use plans for the study area has been synthesized. A logistic regression model was constructed for the study area to estimate the probability of future development for each hectare of undeveloped private land. This model was used to predict the probability of future development for each hectare of undeveloped private land. Technology transfer activities included co-hosting the "International Symposium on Advances in Research for Natural Resource Planning and Management Across Regional Landscapes" at the University of New England, New South Wales, Australia.

**TRANSITION:** Results of this project will further provide the military with techniques, tools, and training to evaluate the impacts of future development and land uses on the environment and to be able to coordinate responses. The tools and methodology will be implemented/transferred to land management issues pertinent to Marine Corps Air-Ground Combat Center (MCAGCC) 29 Palms.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Information Technology Tools for Assessment and Prediction of the Potential Effects of Military Noise on Marine Mammals; CS-1082

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. David Helweg; U.S. Navy Space and Naval Warfare Systems Center – San Diego, CA

**FY 2000 FUNDS:** $355K

**DESCRIPTION:** As concern increases over the expanded presence of man-made sounds in the oceans (e.g. low frequency active (LFA) sonar and ship shock trials), there is limited information on their effects on marine mammals. Actual sound frequency-intensity combinations are suspected of causing damage to the hearing of marine mammals. The objective of this project is to provide information that can guide the assessment and prediction of military noise effects on marine mammals.

The approach of this project consists of three tasks: (1) otopathological analyses of marine mammal ears in general; (2) otopathological analyses of baleen whale ears, the results of which will motivate development of a biomimetic model of baleen whale auditory responsiveness to DoD sound types; and (3) using sensitivity predictions and statistical sampling models and acoustical classification algorithms, to automate the U.S. Navy's Integrated Undersea Surveillance System (IUSS) for mapping the distribution of whales in the Southern California region.

**BENEFIT:** DoD lacks scientifically defensible positions concerning the safe use of LFA and Shipshock testing in the presence of marine mammals. This effort responds directly to the DoD capability to comply with the National Environmental Policy Act requirements and will contribute directly to answering the National Research Council's Research Needs related to the effect of low-frequency sound on marine mammals.

**ACCOMPLISHMENTS:** Sixteen bottlenose dolphin ears from nine individuals and ears from four species of baleen whales were computed tomographcially (CT) scanned and are in various stages of histological preparation. In addition, all magnetic resonance imaging (MRI) scans of five ears were completed. Staining, serial sectioning, and neuroanatomical analysis of the histological preparations were completed for five ears, with four more anticipated by the end of the year. Histology on one humpback whale ear has been completed. A simulated audiogram for humpback whales has been generated by integrating the dense mapping of basilar membrane resonant frequencies with the computational filter-bank model. The "WhalEar" model has been ported to the DoD High Performance Computing system. A library of DoD sound types has been compiled, and predicted sensitivity of humpback whales to these sounds will be completed by the end of the year.

**TRANSITION:** The broad objective is to transition information about the effects of DoD sound types on marine mammal auditory anatomy to predictive models and mitigation tools. The information generated from this project will help identify effects of DoD sound types on marine mammal auditory anatomy to predictive models and mitigation tools.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Assessment of Training Noise Impacts on the Red-Cockaded Woodpecker; CS-1083

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Larry Pater; U.S. Army Corps of Engineers Engineer Research and Development Center, Construction Engineering Research Laboratory – Champaign, IL

**FY 2000 FUNDS:** $400K

**DESCRIPTION:** In this project, the Army is addressing the impact of training noises on the endangered red-cockaded woodpecker (RCW), and developing cost-effective techniques to evaluate and monitor effects of military noise on animal species. These techniques include the capability to characterize noise stimuli, document physiological and behavioral responses, and determine resulting population effects due to military noise.

The approach assumes that proximate effects can be linked to individual fitness, which in turn can be linked to population effects. The proximate response is measured by observing the number of flushing from the nest cavity and feeding behavior (non-nesting). Field studies of the in-situ response of the animal to the measured noise events will be used to determine dose-response relationships. Individual fitness measurements will include: number of young fledged per nest, adult turnover, group size, and mating success. These demographic parameters will be correlated with measured noise levels. Another noise assessment being considered involves correlating historic demographic data with estimated noise levels, using available training noise models. The empirical data from these efforts will be integrated into leveraged RCW population models to assess noise impacts at the population level. Four noise types are considered: artillery noise, small arms noise, helicopter noise, and maneuver noise. (i.e., combination of artillery, small arms, and helicopters.)

**BENEFIT:** The proposed research will provide information required to assess and manage risk to both military training capability and the endangered RCW and other threatened and endangered species (TES) and will provide a factual basis for mitigation and management protocols and guidelines. This will help to alleviate impacts on training capability, avoid the need to acquire additional training land, and minimize litigation and delays.

**ACCOMPLISHMENTS:** Data were gathered to further define RCW response and to improve the statistical rigor of the data set. FY99 data acquisition efforts, guided by the FY98 results, were designed to better define response thresholds for each type of noise. In FY99, a larger proportion of total effort was devoted to defining dose-response relations for maneuver noise, in accordance with the increased emphasis on this type of noise by both the United States Fish and Wildlife Service (USFWS) and military trainers. Considerable data were also obtained to determine the effect of acoustic cavity resonance on the noise level within a cavity. These data will be used to extrapolate noise levels measured at the base of a cavity tree to levels actually experienced by nesting birds. The training activity data required to generate the noise contours for correlation of noise level with RCW productivity was gathered by Ft. Stewart Range Control personnel.

**TRANSITION:** Research results will transition into existing land management decision support tools (e.g. management guidelines for testing and training, and the first audiogram for RCW). Additionally, the results will direct the development of management protocols designed to minimize the impacts to endangered species population from noise generated by military activity.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Error and Uncertainty Analysis for Ecological Modeling and Simulation; CS-1096

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. George Gertner; University of Illinois – Champaign, IL

**FY 2000 FUNDS:** $376K

**DESCRIPTION:** With the growing importance of simulation modeling in natural and cultural resource assessment and management, the Department of Defense (DoD) recognized the need for a comprehensive framework to analyze uncertainty of simulation results. These results are based on estimates of the true parameters and, consequently, are associated with a specific degree of uncertainty. Error budgets can be used to assess the quality of the overall simulation system. Although progress has been made in the areas of uncertainty analysis and error budgets, there is a need to develop the statistical and computational tools to enable model users to jointly assess and quantify the sources and magnitude of errors. These errors are associated with large-scale DoD simulation models used for resource assessment and management. The objective is to develop the methodology for formulating error budgets for environmental monitoring-modeling systems. This project provides the rationale to account for the effect of different sources of error on the uncertainty of model predictions, and the rationale for efficiently reducing that uncertainty.

The approach is to develop an analytical framework and a user-friendly interactive software package to assess and exert control over the quality of the simulation results. This project applies this methodology to a monitoring-modeling system [i.e., Army Training and Testing Area Carrying Capacity (ATTACC)] employed by the military for assessment and/or management of natural and cultural resources at Fort Hood. The project develops a GIS-based methodology to make spatial and temporal predictions, analyze uncertainty, and build error budgets of soil erosion status based on and applied to military training

**BENEFIT:** This project will aid DoD's need to develop a comprehensive framework for quantifying, analyzing and managing uncertainty of modeling and simulation results. Additionally, the project will support general ecological and environmental modeling efforts in the other services.

**ACCOMPLISHMENTS:** This project identified, quantified, and estimated the errors for the environmental component of the ATTACC model calibrated at Fort Hood. Four types of errors have been researched: (1) data errors; (2) data processing errors; (3) modeling errors; and (4) classification errors. The general design specifications for the uncertainty software was developed. NT Super Cluster computers from the National Center for Super Computers (NCSA) were used to develop error budgets due to the great computational time involved for uncertainty assessment.

**TRANSITION:** This capability will provide the necessary quality control/assurance mechanisms to support DoD decision support systems regarding natural and cultural resources. This methodology will be relevant to all users of ecological and environmental models. Specifically, the uncertainty software developed in the project will likely be incorporated into Land Management System (LMS). However, the project will support general ecological and environmental modeling efforts in the other services as well.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Ecological Modeling and Simulation Using Error and Uncertainty Analysis; CS-1097

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Anthony King; Oak Ridge National Laboratory – Oak Ridge, TN

**FY 2000 FUNDS:** $200K

**DESCRIPTION:** Ecological models are often used in conjunction with a geographical information system (GIS). This project is: (1) identifying and evaluating methods for quantifying uncertainty in spatial data for ecological models; (2) incorporating Monte Carlo analysis into a framework for uncertainty and error analysis of spatial data in ecological models; and (3) testing and demonstrating the Monte Carlo framework and tools with a case study.

The general technical approach is to account for the sources and the effect of uncertainty in simulation modeling. The investigation complements the error budget approach and is closely coordinated with SERDP project CS-1096. The Monte Carlo framework is designed as general and modular software to maximize the ease with which alternative ecological models can be incorporated. This approach facilitates application to different installations, ecological models, and applications.

**BENEFIT:** The methods and tools developed by this project will be directly applicable to ecological models used throughout Department of Defense (DoD) and Strategic Environmental Research and Develop Program (SERDP). Incorporation of these methods and tools into the land-use decision process as part of an overall error budget analysis and through land-management systems like Integrated Dynamic Landscape Analysis and Modeling System (IDLAMS) and Land Management System (LMS) will directly benefit the DoD conservation practices and the DoD land-use decision process. The general concepts, methods, and tools resulting from this project will also be available to conservation and land-use decisions on private and public lands managed by other agencies, wherever spatially explicit ecological models are used as part of the decision process.

**ACCOMPLISHMENTS:** The preliminary literature survey for existing methods and approaches dealing with error and uncertainty in spatial data has been completed. Software libraries implementing methods for stochastic simulation of categorical data have been acquired and installed. The approach and preliminary results were presented at the 5th World Congress of the International Association for Landscape Ecology and at the 1999 Annual Meeting of the International Society for Ecological Modeling. The existing methods for dealing with uncertainty in spatial data were reviewed and stochastic simulation was identified as the most appropriate methodology. Software was implemented for stochastic simulation (e.g., GSLIB, GSTAT).

**TRANSITION:** These methods and tools will be incorporated into the land-use decision process as part of an overall error budget analysis, and as part of land-management decision support systems such as the IDLAMS and LMS.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Emerging and Contemporary Technologies in Remote Sensing for Ecosystem Assessment and Change Detection on Military Reservations; CS-1098

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Randall Karalus; U.S. Army Corps of Engineers Engineer Research and Development Center, Topographic Engineering Center – Alexandria, VA

**FY 2000 FUNDS:** $1,130K

**DESCRIPTION:** Federal land managers need accurate and affordable ways to assess the health and availability of their training lands. This research is designed to develop techniques that relate ecological concepts of carrying capacity, vegetation dynamics, critical thresholds, habitat fragmentation, ecosystem response and recovery, and land degradation to the response of remotely sensed spectral indicators, and ultimately, to training and testing upon military installations. The objective is to apply spatial and temporal change detection methods over a range of geographic scales using contemporary and emerging remote sensing technologies and traditional field surveys to identify and monitor land degradation.

Land degradation can be defined in terms of ecological endpoints: a change in plant species composition; a decrease in plant productivity; a reduction in soil quality; accelerated soil erosion; and/or, a change in landscape composition and pattern that affect ecological function. The behavior near or at critical thresholds of one of these five characteristics of land-degradation provide a diagnostic basis for the development of remote sensing-based indicators to estimate ecosystem sustainability. Spectral indicators derived from these endpoints measure the response to training activities on military installations. The approach for this project is essentially a composite of: (1) mapping the installation or select components thereof; (2) correlating the fundamental attributes of disturbance, vegetative cover, and plant succession; (3) analyzing, retrospectively, the ecological history of each installation in relation to land use; and (4) assessing high resolution systems to identify the sensor attributes necessary to monitor changes in plant species composition along disturbance gradients and plant succession stages.

Two types of analyses will be conducted: retrospective analysis, and ecotone and degradation gradient analysis. The purpose is to consider ecosystems in terms of their temporal and spatial characteristics, respectively. The retrospective analysis is a combination of (1), (2), and (3) described above. Whereas, the ecotone and degradation analysis is a combination of (1), (2), and (4). Analyses will be conducted at three facilities: Camp Williams, Utah - Army National Guard; Fort Bliss, Texas - U.S. Army; and, Marine Corps Air Ground Combat Center (MCAGCC), Twentynine Palms, California. Each of these facilities represents three of the four types of desert ecosystems in the U.S.: the Intermountain Cold Desert, Chihuahuan Desert, and Mojave Desert.

**BENEFIT:** DoD remains committed to ecosystem management and assessing mission impacts on their installations supported by an integrated modeling and simulation environment. This capability includes: the National Environmental Database (NED), the Army Training and Testing Carrying Capacity (ATTACC) model, the Ecological Dynamics Simulation (EDYS) model, the Object-Oriented Integrated Dynamic Landscape and Analysis Modeling System (OO-IDLAMS), and the Land Management System (LMS). Installation managers will benefit from standard techniques for cost-effective environmental change detection and extrapolation of field data through the use of remotely sensed data. The capabilities produced by this research will significantly improve the accuracy and cost/time-effectiveness of data collection, monitoring, and modeling for military land management.

**ACCOMPLISHMENTS:** The last of the Landsat scenes were acquired at Ft. Bliss and Camp Williams. The project now maintains an inventory of Landsat data dating back to the early 70's. The inventory includes wet and dry season images for each year. All Landsat images have been purchased and rectified to each

other using a ½ pixel root mean square (RMS) tolerance. The second year of Kodak images were obtained for research transects at Ft. Bliss and Camp Williams. The Kodak digital data was organized and distributed to the project scientists. Also, the second year of CAMIS images were obtained for study transects at Ft. Bliss and Camp Williams. The CAMIS imagery was radiometrically corrected, organized and distributed to the project scientists. A significant amount of field study was conducted and detailed vegetation and soils data were obtained for transects at Camp Williams. Spectral demixing protocols have been developed and tested at Ft. Bliss, TX. Demixing provided accurate estimates of percent cover of shrubs, grasses, and bare ground, and also provided a mechanism by which these estimates could be spatially extrapolated across the installation. A liaison with the environmental officers was established at MCAGCC, study sites selected, and flight transects, which represent the variety of plant communities and kinds of land use impacts on the base, were identified.

**TRANSITION:** The project will acquire an impressive, and to a large degree unprecedented, array of imagery data types for three military facilities (National Guard, U.S. Army, and U.S. Marine Corps). These facilities represent three different desert ecosystems and impacted regimes. The data will provide a baseline against which installation managers can compare future inventories and interventions. This database will not only be available for the installation managers and their environmental staff, but will also be available for further research and adaptation by other research organizations. Deliverables include: models for change detection of land use on military reservations; methods for scale transitions; relationships between hierarchical scheme of spectral and spatial resolution to ecotone/biological thresholds/degradation; protocols for data extrapolation from remote sensing imagery and; a better understanding of ecosystem response and recovery in relation to disturbance (land use).

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Predicting the Effects of Ecosystem Fragmentation and Restoration: Management Models for Animal Populations; CS-1100

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Thomas Sisk; Northern Arizona University – Flagstaff, AZ

**FY 2000 FUNDS:** $175K

**DESCRIPTION:** DoD training and related activities on and adjacent to military lands often contribute to fragmentation and affect species of special concern, including threatened and endangered species. This project proposes to develop species-specific models that predict the responses of mobile animal species in heterogeneous landscapes. Modeling efforts will build on connections between life history characteristics and the responses of mobile animals to habitat fragmentation and restoration. Field research will permit parameterization of models and testing of model predictions, leading to refinement of the conceptual approach. The primary foci are the ponderosa pine forests and riparian habitats on military lands. These two habitat types are widespread throughout the U.S. and currently the subject of great management debate.

This project is a cooperative effort involving Northern Arizona University, Colorado State University, the Ponderosa Pine Ecosystem Restoration Project, the Semi-Arid Land Surface Atmosphere (SALSA) Project, Camp Navajo (U.S. Army and Arizona Army National Guard), and Ft. Huachuca (U.S. Army). There are three areas of investigation being conducted: (1) acquisition of ecological field data on the responses of animals to habitat fragmentation; (2) the mapping of animal habitats in three dimensions and at scales relevant to habitat management; and (3) the linking of empirical ecological data and spatially explicit habitat information in a management-oriented effective area model (EAM).

Habitat mapping will rely on remotely-sensed data and field measurements. Land Remote-Sensing Satellite (LANDSAT) imagery and aerial photography will permit delineation of the spatial extent, shape, and juxtaposition of habitat patches. Important structural attributes will be explored through the use of Synthetic Aperture Radar, aerial photography, and field measurements. Overlay of pertinent data sets in a Geographical Information System environment will allow integration of habitat attributes and identification of floristically and structurally distinct habitat types, as well as the edges that separate different habitat patches. Completed habitat maps will serve as input to the EAM.

**BENEFIT:** The project will link field and remotely sensed data in validated landscape models that will permit comparison of alternative land use strategies on wildlife species of management concern. The model operates in the ARC and ArcView geographic information system environments. Through manipulation of habitat maps, the EAM will be capable of predicting the effects of alternative landscape modifications -- habitat fragmentation due to operational activities, or habitat restoration resulting from rehabilitation or mitigation efforts -- on a wide range of animal species.

**ACCOMPLISHMENTS:** Teams of graduate students and seasonal field assistants set up study sites in the ponderosa pine forests of northern Arizona and in riparian woodlands along the San Pedro river in southeastern Arizona. Crews of 3-4 people focused on birds and butterflies in each ecosystem, working at well over 100 different field sites. The avian field research in these study sites has been completed. Intensive field efforts to quantify bird and butterfly responses to habitat edges were initiated at Mt. Trumbull and Camp Navajo. Field preparation was completed for butterfly field research in riparian woodlands. Modeling efforts focus on automation of data entry in spatially-referenced format, and facilitation of analysis of edge response data. Habitat mapping of desert riparian sites is being accomplished using TMS data along the San Pedro River corridor. Lepidopteran research in desert riparian ecosystem is continuing.

EAM model development focuses on automation of primary analytical tasks within the ArcView Geographic Information System (GIS) environment concentrating on: (1) edge detection and distance-from-edge measurements; (2) identification of edge response functions; and (3) incorporation of response functions in spatial projections of animal abundance levels across modeled landscape.

**TRANSITION:** The project results will be provided to land managers who will link field and remotely sensed data in validated landscape models that will permit comparison of alternative land use strategies on wildlife species of management concern. Extensive field testing of model predictions in different environments will permit evaluations of model effectiveness in forecasting the responses of a wide range of species to landscape-scale alterations in forested and riparian habitats.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Improved Units of Measure for Training and Testing Area Carrying Capacity Estimation; CS-1102

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Alan Anderson; U.S. Army Corps of Engineers Engineer Research and Development Center, Construction Engineering Research Laboratory – Champaign, IL

**FY 2000 FUNDS:** $600K

**DESCRIPTION:** This project proposes to significantly improve the Army Training and Testing Area Carrying Capacity (ATTACC) methodology of an installation management tool to better predict the environmental consequences of military training activities. The focus of this project is to develop quantitative units of measure (such as erosion and species composition on land) to estimate training and testing land carrying capacity, extend the spatial and temporal scale of the methodology to include individual training areas and changes in training and land condition throughout the year, and validate the improved methodology.

In the existing ATTACC methodology, erosion status is estimated using the Revised Universal Soil Loss Equation (RUSLE). The RUSLE equation was developed for agricultural lands and does not account for complex topography that is typical of military lands. The unit stream power approach for estimating the topographic factor of RUSLE will be used to account for complex topography typical of military lands. This project will extend the current ATTACC methodology to include wind erosion in addition to water erosion. Existing wind erosion models will be evaluated to determine which is the most applicable to military lands based on data requirements and model assumptions. The results from the completed SERDP project CS-752, Terrain Modeling and Soil Erosion, are being used to improve estimates of land condition and can be extended to off-site impacts (sedimentation and water quality). ATTACC methodology is being expanded to include plant species composition as a measure of land condition. To incorporate species composition into the ATTACC model, the Ecological Dynamics Simulation (EDYS) model, (i.e., a process-based model that predicts changes in species composition that naturally occur over time and in response to natural disturbances) will be utilized.

A sub-model will be developed for the EDYS model, that translates training/testing activities into changes in soil and vegetation processes. Existing DoD impact studies are used to estimate the primary impacts of military activities on soil and vegetation processes. The ATTACC methodology also will be extended to account for climatic variation throughout a year. Components of the ATTACC model will be modified to incorporate time varying climatic factors. Temporal differences in mission impacts on the vegetative cover factor will be estimated from existing DoD impact studies.

The following are enhancements that have been incorporated into the ATTACC model: (1) Water Erosion Model; (2) Wind Erosion Model; (3) plant species composition; and (4) time varying climatic factors.

**BENEFIT:** By providing an improved methodology, mission impacts can more accurately be matched to the ecological capability of military lands to support those activities resulting in decreased land maintenance costs, maintaining realistic training conditions, and increasing land use capacities.

**ACCOMPLISHMENTS:** A sensitivity analysis of the ATTACC model was completed. The unit stream power approach for estimating the topographic factor of RUSLE is being utilized. Software that implements the ATTACC model improvement is in testing. User manuals, tutorials, and related documentation are being developed.

The following have been incorporated and/or improved in ATTACC model: (1) Water Erosion Model and (2) Wind Erosion Model. The evaluation process, results, and model limitations are drafted. Results were published in an erosion workshop proceedings (R. Nelson, E.L. Skidmore, and A.B. Anderson. 1999. Comparison of Wind Erosion Models. 10th International Soil Conference Organization, May 1999, Purdue University).

The EDYS model was selected to incorporate plant species composition into the ATTACC model. A military impact component of the EDYS model was developed.

**TRANSITION:** This project will feed into the current ATTACC methodology to include wind erosion, land condition, and plant species composition. Researchers are actively involved in the Army Corps of Engineers' Land Management System (LMS) initiative and are currently participating in the Fort Hood LMS Military Demonstration and activities of the LMS Integration Team. Project activities are coordinated with several DoD user groups including (1) the ATTACC Wind Erosion Advisory Group, (2) ITAM Installation Steering Committee, and (3) ATTACC Working Group. Team members have also been asked to serve on the United States Department of Agriculture (USDA) WEPS advisory group.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Identify Resilient Plant Characteristics and Develop a Wear Resistant Plant Cultivar for Use on Military Training Lands; CS-1103

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Antonio Palazzo; U.S. Army Corps of Engineers Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory – Hanover, NH

**FY 2000 FUNDS:** $400K

**DESCRIPTION:** Wear-resistant plants are needed to mitigate environmental impacts and improve the use of Department of Defense (DoD) training lands. Knowledge of the relationships between military training and plant injury, regrowth, and wear resistance is limited. Plant and soil data will be combined allowing land users to make knowledgeable choices concerning plant selection and site-rehabilitation procedures to reduce soil erosion. This project intends to use several collections of resilient and other plants to breed new more resilient cultivars. A second objective is to conduct field and greenhouse studies to quantify the degree of compaction that occurs during training and relate soil condition to root injury in plants with known resilience.

The technical approach for this project begins with the identification and development of training-resilient plant cultivars. Field and greenhouse studies will be conducted to quantify the degree of soil compaction that occurs during training, relating this soil condition to root injury in plants with known resilience. The greenhouse study is on soil compaction and plant root growth. Three species are being studied (Reliant hard fescue, Blackwell switchgrass, and western wheatgrass) and three compaction levels in six soils. The field study is evaluating a naturalized cultivar ('Vavilov' Siberian wheatgrass, *Agropyron fragile*) and two native cultivars (Goldar bluebunch wheatgrass, Pseudoroegneria spicata and 'Secar' Snake River wheatgrass, *Elymus wawawaiensis*) which were seeded in mixtures and in several different row-space combinations to determine if rapidly establishing naturalized and native species can be established together.

**BENEFIT:** This project will provide DoD guidance for mitigation methods in restoring training lands and will provide more resilient plant species that will help to increase training opportunities on existing training areas. This guidance will assist land managers and trainers in making choices on training schedules and in estimating cost and time requirements for maintaining military readiness.

**ACCOMPLISHMENTS:** Approximately 500 lbs. of a Russian wildrye experimental strain (Syn-A) was produced and will be made available to the Army through this project. A rhizomatous cultivar of crested wheatgrass ('RoadCrest') was released and registered in "Crop Science."

Field and greenhouse studies are being implemented to evaluate seed mixtures with naturalized species producing an early cover crop to help establish their native counterparts.

**TRANSITION:** The results and findings of this project can be expanded to include the development and testing of additional plant species on a variety of soil types. This will provide opportunities for widespread application/demonstrations of this information to other testing and training ranges. This project will provide valuable information for organizations outside of DoD who deal with plant resiliency and soil compaction problems, as well.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** SERDP Ecosystem Management Program (SEMP); CS-1114

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. William Goran; U.S. Army Corps of Engineers Engineer Research and Development Center, Construction Engineering Research Laboratory – Champaign, IL

**FY 2000 FUNDS:** $2,656K

**DESCRIPTION:** The SERDP Environmental Monitoring Program (SEMP) was established as an outgrowth of the 1997 SERDP Management Scale Ecological Research Workshop during which it was determined that the DoD should establish a long-term ecological monitoring program at a military base with possible expansion to some other bases in the future. The overall program objective of SEMP is three-fold. First, SEMP directs and selects DoD relevant, ecosystem management research initiatives. Secondly, it manages a long-term ecological monitoring system(s) to support these research efforts while also fulfilling some of the host installations monitoring requirements. Finally, SEMP facilitates the integration of results and findings of research into DoD ecosystem management practices. The SEMP is managed by a separate Program Manager with the assistance of a Technical Advisory Committee (TAC).

Under the Ecosystem Characterization and Monitoring Initiative portion of the program, a team works with the host installation to gather, assess and document historic and current ecological data sources and monitoring efforts. In addition, this team is responsible for long term ecological monitoring. Data from the characterization effort, the monitoring efforts and the research teams all flows into the common data repository, shared by all research teams and the installation managers.

Selected research teams work in a collaborative context -- sharing field sites and approaches, entering data into a common repository, reviewing each other's findings, and contributing to common technology transfer mechanisms.

**BENEFIT:** DoD's Conservation user community is directed to implement an ecosystem approach to land management issues. However, there is a critical need for scientific information to support this approach, especially as it relates to integrating ecosystem management with mission concerns. The success of user plans will depend on the capabilities and increased knowledge generated by research investment. SEMP will facilitate a number of studies that can be sufficiently planned and funded to allow a full array of remote sensing, ground truth experiments, modeling, cause-effect studies, etc. to be integrated to address complex problems. This contributes to data sharing, leveraging, and joint publications, supported by major experimental findings. Focused development of an ecosystem research plan, appropriate instrumentation and monitoring to support this research, and identification and selection of the most effective, technically sound research efforts to answer user needs will all contribute to the science and understanding necessary for an ecosystem approach to land management.

**ACCOMPLISHMENTS:** During FY99, an inventory was completed detailing relevant ecological data and information available for Fort Benning, GA (the initial SEMP host site) and the surrounding region. Two workshops were conducted to help identify data and information requirements important to land managers and ecological researchers. The ECMI design document was completed having been reviewed by the Technical Advisory Committee (TAC) and external peer reviewers. The document includes: (1) providing and characterizing existing data and data sources; (2) designing and implementing a baseline monitoring program; (3) establishing and maintaining a data repository; and (4) adapting the monitoring program based on new research findings or installation requirements.

SEMP information is now available through the SEMP website (http://www.denix.osd.mil/SEMP). All documents, briefings and meeting minutes have been posted at this site, located under the Defense Environmental Network Information eXchange (DENIX).

In FY99 three research teams that are addressing Ecological Indicators of Change have provided detailed work plans, selected field sites, and initiated sampling and monitoring efforts. One of the teams developed a procedure for ecological indicator selection based on a hierarchical framework and management goals. Criteria for the selection of ecological indicators have been defined. The research teams are collaborating and coordinating their efforts with each group as well as the ECMI team.

The FY00 Statement of Need (SON) entitled, "Ecological Disturbance in the Context of Military Landscapes," was released. The objective of the SON is to develop the knowledge required to implement adaptive ecosystem management approaches for military lands and waters, as well as other Federal facility lands and waters. Two research teams were selected to support the FY00 SON.

**TRANSITION:** Project results will be integrated into DoD ecosystem management policy and procedures to provide DoD land managers the necessary guidance and tools for a sustaining future military training and testing. The monitoring and research results will also be available to other Federal land managers.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Dynamic Modeling of Military Training Impacts and Archaeological Site Distributions in Evolving Landscapes; CS-1130

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. James Zeidler; Colorado State University – Fort Collins, CO

**FY 2000 FUNDS:** $100K

**DESCRIPTION:** This "proof-of-principle" study addresses the ability to effectively model and predict the distribution of archaeological (including prehistoric, historic, and traditional cultural property) resources on military and Department of Energy (DOE) lands and ranges, and address the potential or probability of unique impacts that adversely affect those resources. It is aimed at (1) demonstrating the effectiveness of a 3-D computer simulation approach to predictive archaeological modeling and resource risk assessment, and (2) demonstrating that the approach is transferable to other installations or facilities where these resources are at risk from three-dimensional (subsurface) impacts.

**TECHNICAL APPROACH AND RISKS:** The approach can be characterized as "volumetric" in nature in that it develops a three-dimensional predictive model of archaeological site location based upon geomorphic process modeling of landscape evolution, detailed geomorphic sampling, and paleoenvironmental reconstruction. The net result is a three-dimensional computer simulation model that highlights "archaeological risk surfaces" of varying magnitude or likelihood in terms of their specific geomorphological context on a given landscape. The 3-D modeling builds on the Channel-Hillslope Integrated Landscape Development (CHILD) model developed by the Massachusetts Institute of Technology in collaboration with the U.S. Army Corps of Engineers Engineer Research and Development Center – Construction Engineering Research Laboratory. The CHILD model output provides a quantitative geomorphic context for interpreting the space/time correlations among archaeological materials in the alluvial basin by simulating the processes of dispersal by erosion and burial by deposition.

Interpretation and validation of simulation results are carried out using the empirical geomorphological data from extensive subsurface geoarchaeological testing (e.g., profile cutting, backhoeing, coring, etc.) previously carried out on the test drainage at Fort Riley. This will result in the development of 3-D "archaeological sensitivity" maps that can then be compared with the existing 2-D predictive model of the same drainage for an evaluation of relative predictive accuracy and ultimate utility for land management purposes.

**BENEFIT:** Implementation of this 3-D approach to the archaeological record and the simulation results of the CHILD model can be extremely useful to the cultural resource specialist in several ways. By simulating the process of erosion and deposition of sediments across a river catchment in time, the model provides a powerful tool for visualizing the dynamic nature of landforms. Within this dynamic framework, hypotheses regarding prehistoric human activities and settlement locations can be demonstrated and tested. Additionally, by calibrating the model to a specific reach of a valley using available information on the local hydrologic history and lithology, the model has potential for reconstructing the spatial extent of archaeologically important sediment features, such as paleosols, along the valley and in between geoarchaeological cross-sections. In this way, it can aid in the development of reliable 3-D archaeological sensitivity maps.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** Transferability of this approach to other installations and landscapes will be examined in terms of an evaluation of the minimal paleoenvironmental and geoarchaeological data requirements for successfully calibrating and validating the simulation exercises.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Diagnostic Tools and Reclamation Technology for Mitigation Impacts of DoD/DOE Activities on Arid Areas; CS-1131

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. W. Kent Ostler; Bechtel Nevada – Las Vegas, NV

**FY 2000 FUNDS:** $595K

**DESCRIPTION:** This project is designed to overcome current gaps in diagnostic capabilities needed to distinguish between various degrees of sustainable and non-sustainable impacts due to military training and testing or earth-disturbing activities in desert ecosystems. Additionally, the project aims to develop and evaluate new and cost-effective techniques for rehabilitation and restoration of such disturbed habitats.

The technologies being evaluated and tested are divided into two principal areas: diagnostics and restoration techniques. For diagnostic techniques, new rapid detection methods will be developed using hand-held digital cameras and Hi-8 camcorders to record selected ground data such as panoramic views with vertical and horizontal scale references to record shrub height and canopy width, regularly-spaced closeups to document shrub sprouts, percentage of shrubs alive, emergence of seedlings, and morphological demographic data (approximate proportion of shrubs at different ages or sizes). Images shot from helicopter or fixed-wing aircraft along selected or permanently marked flight lines can be evaluated using computer technologies to provide rapid assessment of vegetation such as total number of shrubs and cover present in selected areas. For example, using aerial photography of a scale from 1:2,000 to 1:24,000 it is possible to selectively scan a photograph and process the image data to rapidly calculate shrub density and total shrub cover in less than a minute per plot. Additionally, data are analyzed statistically to show size classes of shrubs, a parameter important for assessing impacts from training exercises and shrub demographics.

The site potential for restoration is determined by such things as plant species present, seed bank, soil moisture, and nutrients. At some sites, a shift in the plant community composition may also occur, with more sensitive species being replaced by plants that are more resistant to training impacts. Recovery may occur naturally and keep pace with the level of disturbance at some sites, depending on the nature and frequency of the disturbance, or it may require selected restoration techniques to recover from adverse training impacts before sustainable restoration is achieved.

**BENEFIT:** Approximately 70% of all U.S. military training lands are located in arid areas that will benefit directly from these technologies. Under current technology, it is estimated that up to 35% of revegetation projects will fail. Applying the results of this project will increase the success of the restoration and possibly save DoD as much as $5 million annually. These diagnostic tools will enable management to maximize utilization of limited training environs and thus increase operational readiness.

Technologies developed by this program can be used for a variety of applications currently needed by government agencies with land management responsibilities in both arid and moist environments. The primary applications include: (1) evaluating and monitoring the site's ability to recover from various levels of impacts, (2) rapidly assessing shrub density, height, diameter, size class and percent canopy cover (important for controlling erosion), and (3) developing cost-effective revegetation techniques.

**ACCOMPLISHMENTS:** The research team has completed a detailed management plan which has been reviewed by its Technical Advisory Committee (TAC), a group of 7 prominent scientists from academia and agencies. An initial workshop was successfully conducted in which future users of the technology were invited to attend. Images have been acquired from several user sites, (i.e., Yuma Proving Ground, Fort Irwin, Camp Williams, Fort Hood, Nellis Air Force Range and Nevada Test Site) to test the applicability of the

software at various sites and scales. Satellite imagery of Fort Irwin was gathered to evaluate correlations between aerial photography processed with the image analysis software and satellite imagery.

Five study areas were selected at Fort Irwin to conduct the reclamation research trials. Soil and water samples have been taken and seed and reclamation supplies have been acquired. The study design, presented at the workshop, has been refined based on input from other reclamation professionals as well as a statistician.

**TRANSITION:** These results will be integrated into land management decision support tools to provide DoD land managers the necessary guidance for mitigation methods that will help to increase training opportunities on existing training areas (e.g., hydrologic models are currently being developed for Nellis Air Force Base and the Nevada Test Site).

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Direct Detection of Archeological Sites Using Remote Sensing; CS-1142

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Paul Buck; Desert Research Institute – Reno, NV

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** The objective of this one-year pilot study is to improve the identification and assessment of prehistoric, historic, and traditional cultural properties for sites on Department of Defense (DoD) and Department of Energy (DOE) lands. This study will partially address that need by identifying the type of archaeological materials that can be detected remotely. The focus of the research is to determine if ceramic and obsidian artifacts are theoretically and practically detectable given the characteristics of the measuring instruments and spectral contrasts between targets and typical backgrounds.

The technical approach involves measuring the spectra of obsidian and ceramic artifacts under field and laboratory conditions. The data will then be used to support a "detection limits" model to predict what kinds and amounts of materials are theoretically detectable with any given remote sensing device. Field spectra of representative background and target materials from study sites at China Lake Naval Air Weapons Station (CLNAWS) and Los Alamos National Laboratory (LANL) will be collected using two thermal infrared (TIR) and one visible/near infrared (VNIR) instruments.

Through the use of a reference library of actual spectra of target and background materials collected from the two study sites and given the instrumental limits of scanner systems, the detection limits of various target materials will be established. The detection limits approach will also be used to identify which wavelengths are needed for discrimination of obsidian and ceramics from background and other foreground materials.

**BENEFIT:** If ceramic and obsidian archeological material is remotely identifiable, then these spectral and spatial data can be used to locate archaeological sites which are now only identifiable by pedestrian survey. Comparison of remotely sensed data from different platforms at different spectral and spatial resolutions may show that certain kinds of sites can be reliably detected using widely available relatively inexpensive remotely-sensed data.

**ACCOMPLISHMENTS:** Field studies were completed at CLNAWS and at LANL. Data were also collected on typical backgrounds, including soils, rock, plant materials, and living vegetation. A variety of sediment/soil samples were collected, both from CLNAWS and LANL for submittal to Jet Propulsion Lab for thermal analyses.

The field data were successfully downloaded and are currently at the University of Washington Geological Remote Sensing Lab undergoing analysis.

**TRANSITION:** The methodology, data results, and model development can be applied at any DoD installation expected to have buried ceramic and obsidian artifacts.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Application of Hyperspectral Techniques to Monitoring & Management of Invasive Weed Infestation; CS-1143

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Susan Ustin; University of California – Davis, CA

**FY 2000 FUNDS:** $411K

**DESCRIPTION:** The rapid spread of non-native invasive plant species, including noxious weeds is causing irreparable damage to the natural resources on military installations. This project aims to develop and demonstrate a new remote sensing methodology using hyperspectral imaging (HSI), for mapping invasive weeds.

Seven bases have been selected that have different weed types, intensities, and patterns of environmental disturbances from the southeast, southwest, and northwest ecoregions of the U.S. to demonstrate, refine and validate the proposed methodology. These case studies will demonstrate the portability of the methods under conditions of different types of military activities. Wall-to-wall maps will not be developed. Instead, appropriate airborne flightlines that include a range of types of weed problems on the base, intensity of invasive weeds, and encompass a range of land use conditions will be identified. These data will provide a basis for demonstrating and assessing the benefits of HSI data for mapping various species of weeds under the diverse conditions existing at each of these military bases.

New support vector machine learning tools will be used to characterize the habitats and identify weeds in the HSI imagery. The Hierarchical Foreground Background Analysis (HFBA) is one example of a multi-scale resolution analysis that is used to link the spectral variation for each pixel with variation in the spatial domain. The HFBA decomposition is coupled with a wavelet-based, multi-scale resolution in the spatial domain. This method addresses three issues regarding spectral features which are not addressed by standard methods of image analysis that focus on each pixel separately. Spectral redundancy, the span and completeness of a supervised classification, and a mechanism for producing an automatic classification are the key issues to be addressed. The combination of HSI tools for analysis of field spectra and images will provide a robust protocol for monitoring ecosystems that can be applied, even when the specifics of the location and the nature of the invasive species changes. The tools will be compatible with existing Land Management System (LMS) environmental management models.

The methods will be tested on bases in the southwest, northwest, and southeast U.S. Our species discrimination approach to analysis of HSI data will use linear mixing analysis where appropriate and more advanced non-linear image analysis and other linked spatial-spectral analysis procedures, like wavelet decomposition and multi-scale resolution procedures to discriminate the weed from the environmental background. The HSI information will be integrated into a Geographic Information System (GIS) database of other site characteristics to develop a predictive model of potential for weed invasion.

**BENEFIT:** The immediate benefit of this project will be a better understanding of the distribution of major invasive weeds on military bases and the environmental conditions associated with their distributions and spread. The long-term benefit will be in developing a cost-effective method for mapping weeds that can be used to monitor spread of weeds to new locations. Current methods are labor intensive and slow; new methodologies should improve timeliness and cost for information on the distribution of weeds. The invasive weed potential model will allow managers to evaluate land use and other management options on the spread of invasive weeds. It will provide a basis for efficient management of natural resources by targeting the most likely sites for weed invasions.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** Demonstrations of the tools will be provided to site personnel and written technology transfer documents and a web based training course as part of the technology transfer objectives will be developed. The image analysis and other software tools to be developed are compatible with GIS based management protocols and compatible with LMS software.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Exotic Annual Grasses in Western Rangelands: Predicting Resistance & Resilience of Native Ecosystems Invasion; CS-1144

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Jayne Belnap; National Park Service; Canyonlands Field Station – Moab, UT

**FY 2000 FUNDS:** $312K

**DESCRIPTION:** Much research effort has gone into documenting the dynamics of non-indigenous grass invasion and dominance. However, what makes a system susceptible to invasion is still not known. While physical disturbance appears to play a role, many disturbed areas are not invaded, while many undisturbed areas have been invaded. This project proposes to (1) determine if the current distribution of cheatgrass (*Bromus tectorum* - an invasive species) and other annual grasses can be predicted on a landscape and regional level using soil chemistry; (2) construct a model that predicts which soils are resistant or susceptible to annual grass invasion for a large watershed; (3) investigate positive feedback loops that may perpetuate annual grass dominance, such as altered soil organic matter, litter, or chemistry; and (4) examine ways to favor native plant re-invasion by altering soil chemistry.

The initial focus will be the random selection and sampling of sites. These sites will represent major habitat types (based on vegetation and soil types) within the watershed surrounding Virginia Park. At each site, slope, aspect, elevation, soil type, past and present anthropogenic disturbance and distance to roads will be noted. Cover of vascular and non-vascular vegetation will be estimated. Soil depth and stability will be assessed. Soils will be analyzed for texture, total nitrogen, phosphorus, potassium, magnesium, calcium, sodium, manganese, copper, iron, zinc, cation exchange capacity, electrical conductivity, pH, percent calcium carbonate, and organic matter. Soil food webs will be analyzed as well. Magnetic properties, which indicate the presence of windblown dust, will be measured. Regression analyses will be done to see what factors best predict the presence of *Bromus*. If nothing is found to predict Bromus presence, the above will be repeated in an area of winter-rain only.

This project will coordinate with other existing SERDP projects. The research team will utilize distribution data collected by CS-1143 to test prediction of *Bromus* distribution with soil chemistry. Additionally, this research team will utilize soil data from CS-1145 to test the model resulting from this project.

**BENEFIT:** With many millions of acres currently dominated by non-indigenous annual grasses, and 62 million acres of rangeland habitat highly susceptible to conversion, annual grasses are emerging as a major factor to be considered as the future of rangeland ecosystems are being evaluated. This project will aid managers in predicting what soils are susceptible to invasion by aliens and facilitate re-establishment of lost habitat. In addition, understanding how annual grass invasion changes natural ecosystem processes, such as nutrient availability, water availability, and soil microbial systems and how these changes affect re-establishment of native perennial plants, will enhance efforts to restore lost habitat. Preventing *Bromus* invasion is important to the military mission. As native vegetation is replaced by annual grasses through competition or wildfire, the complex horizontal and vertical structure of the community are replaced with a very simple and low structure, thus making realistic military maneuvers more difficult. Annual grasses are highly flammable, thus decreasing the ability to use an area without incurring the cost and damage of wildfires. The existence of endangered species can result in curtailed activities.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** Products from this project will include datasets, metadata, technical reports, scientific publications and field consultations with land managers. Printed and digital media will be used for distribution.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Integrated Control & Assessment of Knapweed & Cheatgrass on Department of Defense (DoD) Installations; CS-1145

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Mark Paschke; Colorado State University – Fort Collins, CO

**FY 2000 FUNDS:** $402K

**DESCRIPTION:** The objective of the proposed research is to develop a strategy for the control, monitoring and prediction of knapweed and cheatgrass infestations on DoD installations in the Western U.S. Large areas of the Western United States are infested by knapweed and cheatgrass species and they are a major concern for military bases. Heavy maneuvering by troops and equipment causes large disturbances. Where native vegetation is stressed, soil is lost, and invasive noxious plants often take hold. Replacing stands of noxious weeds with native plant communities on military training grounds will reduce soil erosion and create more sustainable ecological systems. Non-indigenous invasive plants can also reduce and destroy forage for livestock and wildlife, displace native plant species, reduce recreational opportunities, and can poison domestic animals. It is imperative to find economical, ecologically sound methods to control these weeds to minimize control costs and degradation of military training grounds.

This project will evaluate the combined effects of several innovative measures as a means of controlling, monitoring and predicting some of the most problematic non-native weed infestations in the Western U.S.. The ultimate plan for the project is to combine methods that are known to be partially effective at controlling these species with innovative new approaches. The project will combine biological control using insect pathogens, fire, manipulation of soil N availability, seeding with native late-seral species, and restoration of the soil community in a replicated partial factorial arrangement of test plots in established communities of cheatgrass and knapweed at two military installations. The results of these manipulations on plant community composition will be monitored over a four-year period in order to evaluate success. Results from our study will be incorporated into an existing ecological dynamics simulation (EDYS) model. The EDYS model will be calibrated to each of the field study sites to assess the direct and indirect effects of treatments on ecosystem dynamics at multiple spatial scales, and to project potential effects of treatments on long-term successional dynamics. By integrating remote sensing methods for evaluating noxious weed abundance into this work, we will test an innovative method of monitoring population densities of these weed species, a method that shows much promise for large-scale monitoring.

**BENEFIT:** This project will provide be a new effective methodology for controlling non-indigenous invasive plant species. The overall long-term benefit will be reduction of knapweed and cheatgrass populations on military installations and other lands, and a return of native plant communities to provide more realistic training areas and thus improve mission readiness.

Another benefit of this research is basic information on the ecology of weed infestations. Numerous and detailed observations on weed biology, biocontrol performance, plant community ecology and soil ecology will be integrated with these studies. Results of these detailed observations will be used to further refine control strategies for cheatgrass, knapweed, and other weed species in ways that we cannot anticipate.

New methodology for assessing the status of cheatgrass and knapweed populations from remote platforms will be an additional benefit from this work. The development of a multispectral remote sensing technique for detecting and monitoring cheatgrass and knapweed will be a valuable tool for installation managers. This cost-effective tool will allow resources to be directed more efficiently and thus improve readiness capabilities. Another important benefit of this work will be the enhancement of an EDYS model for projecting management alternatives for cheatgrass and knapweed infestations. This model is already being developed as a management tool for use on military installations. This SERDP project will result in an

improved version that can be used specifically to evaluate management alternatives involving cheatgrass and knapweeds in order to better manage training activities and improve mission readiness.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** Resulting methodology for controlling these weeds will also be made available to others by the means of peer-reviewed journal articles, web pages, and presentations at scientific meetings and symposia. This project will result in an improved tool to evaluate management alternatives involving cheatgrass and knapweed in order to better manage training activities and improve mission readiness on military installations.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Developing Biological Control of Garlic Mustard; CS-1146

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Bernd Blossey; Cornell University – Ithaca, NY

**FY 2000 FUNDS:** $162K

**DESCRIPTION:** Garlic mustard (*Alliaria petiolata*) is one of the most serious invasive species in the Northeast, Southeast and Midwest replacing native spring wildflowers in forest communities. Physical, mechanical, and chemical means have failed to provide long-term control. The development of biological control appears the only viable option for ecologically sound management of garlic mustard. This project proposes to study ecology, life history and impact of insect herbivores. The development of a standardized long-term monitoring plan is an essential objective of the project to assess the impact of released biocontrol agents on target plant and associated plant communities. This project additionally proposes to implement a standardized monitoring protocol for follow-up studies incorporating target weed, insect control agents and native plant communities.

Personnel at CABI Bioscience Center Switzerland will begin detailed investigations on the ecology, life history and impact of 5 potential biocontrol agents for garlic mustard in Europe and determine their host specificity. They will provide details of the life history (phenology, competitive interactions, natural enemies) and impact on plant growth and population dynamics by potential biological control agents of garlic mustard. An important focus of the investigations will be changes in plant growth or biomass allocation of garlic mustard in response to different densities of control agents. In addition, the influence on plant performance as a result of attack by single or multiple species (i.e., on above and below ground plant tissues) will be assessed in the field and in common garden experiments. These studies of herbivore interactions will help determine whether the introduction of multiple agents is warranted or should be avoided.

To assess the impact of the release of biocontrol agents on garlic mustard and native plant communities, a standardized monitoring protocol will be developed. Potential field sites will be visited and long-term monitoring sites will be established. Data will be collected on garlic mustard performance (height, seed production) and abundance (presence/absence, number of stems, cover, biomass) at sites in North America (no specific herbivores) and in Europe (with host specific herbivores). Basic site specific parameters (exposure, overstory species, soil types etc.) will be recorded to evaluate the influence of habitat types on the control success. Measures of control agent abundance (and of native insects or pathogens that may occur on garlic mustard) and damage will be recorded in abundance and damage classes. Data collections will occur in spring and fall and the most meaningful parameters will be selected for continuation at the end of the first field season.

**BENEFIT:** Military installations throughout the country provide important refuges for rare and endangered species. The spread of invasive plants threatens the ecological integrity of these areas and installations are charged with the development and implementation of ecologically sound management practices. The development and implementation of biological weed control programs, e.g. the introduction of host specific herbivores from the native range of a non-indigenous plant species, offers an ecologically sound, cost-effective, long-term management strategy that will help protect native species and their habitats.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** This protocol will be used by researchers and natural resource managers at military installations and other agencies to monitor the success of control agents after their release in North America. Workshops and manuals will be used to introduce resource managers to the application of biological weed control and in the use of the monitoring protocol.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Analysis of Desert Shrubs Along First Order Channels on the Desert Piedmonts: Possible Indicators of Ecosystem Health & Historic Variation; CS - 1153 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Eric McDonald; Desert Research Institute – Reno, NV

**FY 2000 FUNDS:** $88K

**DESCRIPTION:** The primary objective of the proposed project is to determine if key shrub and tree species distributed along first-order channels draining desert piedmonts can provide efficient and reliable signals of environmental change and desert ecosystem health resulting from both natural disturbance and/or military activities. The project will be focused on the extensive areas of desert piedmont at the US Army Yuma Proving Ground, Arizona; but the overall concepts and technical approach will be applicable to many Federal installations in the desert southwest. Additionally, this project addresses three specific objectives: (1) determine historic range in variation (HRV) of key desert vegetation common to alluvial fan surfaces and first-order rills, including HRV, due to military activities and natural environmental change; (2) evaluate if changes in soil and surface hydrology, due to either military activities and natural environmental variation, can be shown to predominantly account for changes in ecosystem health, especially the historic contraction of vegetation along the margins of alluvial fan surfaces; and (3) provide recommendations that can be used to further develop and test methods or procedures that can be used to monitor ecosystem status and identify impacts related to natural disturbance relative to military activities.

Results of soil, geomorphic, hydrologic, and biologic characterization will be integrated to test the hypothesis that the distribution of desert shrubs along first-order channels can be used as an indicator of the historic range of variation and of overall ecosystem health. Two first-order drainage basins will be selected for this study. Drainages will cover approximately 500 to 1000 $m^2$ and will consist of drainage areas that have a nearly continuous cover of desert pavement (before any disturbance). One basin will drain an area with minimal disruption from military activities (natural basin); the other basin will drain an area that has been extensively disrupted by military activities (impacted basin), especially degradation of the soil and pavement by tracked vehicles.

**BENEFIT:** Results will directly the advance knowledge of fundamental soil-hydrology-vegetation processes that are common to desert piedmonts. Evaluation of critical linkages between soils, soil water balance, and desert plant ecology will provide key information about the impact of climate and military activities on desert shrubs, soils, and archeological sites. Results will provide information about how potential changes in the soil and desert pavement surface from military activities may influence other parts of the desert ecosystem.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** The results will be used to support immediate land use/management decisions at U.S. Army Yuma Proving Ground (YPG), Arizona. The overall concept and approach has limitless applicability at other arid/semiarid DoD sites as well. Prepare recommendations for how results may be incorporated into YPG resource management and training strategies. Guidelines will be formulated for applying soil and geomorphic data for predicting impacts of military activities on vegetation along low-order drainages as well as how to monitor for natural change in ecosystem health. Papers will also be submitted to professional journals.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Measures of Ecological Integrity for Salmonid Streams in the Pacific Northwest; CS-1154 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Christopher May; University of Washington, Applied Physics Laboratory – Seattle, WA

**FY 2000 FUNDS:** $79K

**DESCRIPTION:** Military bases in the Pacific Northwest (PNW) contain valuable aquatic habitat that supports several threatened or endangered species of salmonid. The goal of this project will be to determine a suite of ecological-based indicators for freshwater, aquatic ecosystems to measure environmental change resulting from a shift in natural disturbance regime due primarily to the cumulative effects of watershed development in general, and military operations in particular.

The research team will investigate a range of physical, chemical, and biological parameters that could be used as tools for assessing changes in natural, aquatic ecosystem structure and function resulting from military activities within the study watersheds. Additionally, the team will evaluate existing stream/wetland assessment protocols used in the region for applicability to military installations and their associated natural resources. These will include Federal, state, local, and tribal agencies charged with similar responsibilities. Based on watershed analysis and field surveys, a multi-metric suite of ecological indicators will be developed.

The project will generate a regional database relating the degree of watershed disturbance and ecological integrity to salmonid utilization, including abundance and species composition, and instream habitat quantity and quality. A management framework will be developed for stream ecosystem protection and restoration based on active management for natural ecological integrity. This framework will guide military and civilian resource managers in interpreting measurable ecological parameters toward design of effective ecosystem rehabilitation, enhancement, and preservation efforts. A set of guidelines will also be established for the various military operations identified to minimize their impact on aquatic resources. The project will establish a standard suite of protocols to measure physical (hydrologic, geomorphic, and habitat related), chemical, and biological components of ecological integrity for streams found on military installations in the PNW region. Habitat assessment protocols will focus on instream salmonid habitat and riparian/streamside forest habitat. A standard set of assessment protocols will allow for comparison of watersheds as well as meeting regulatory requirements.

**BENEFIT:** In the long-run, based in part on this project, Department of Defense (DoD) installations in the PNW will be able to be proactive in section 7 ESA consultations. This will mean more certainty of uninterrupted military operations and training as well as preserving and enhancing aquatic habitat under DoD stewardship. This research will facilitate DoD installations becoming leaders in managing salmonid populations in watersheds under their jurisdiction and allow base commanders to work seamlessly with state and local jurisdictions on watershed planning and salmon recovery plans.

Specifically, the project will result in a PNW regional database of watershed ecological integrity with respect to salmonid utilization and habitat conditions, a list of human activities which have an impact on native salmonid populations as well as aquatic ecosystems within DoD jurisdiction, a Guide to Aquatic Ecosystem Habitat Assessment for DoD installations in the PNW, and a set of guidelines for natural resource managers and environmental program directors with regard to stewardship of aquatic ecosystems and salmonid resources on DoD installations in the region.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** The resulting management framework will have potential use over a range of environmental conditions found on DoD installations in the PNW. A set of guidelines will be established for various military operations to be used by DoD installations to minimize their impact on aquatic resources. The results of this research have high transition potential with respect to cost-effective application to a wide range of DoD facilities in the PNW and other regions of the country.

# PROJECT SUMMARY

**PROJECT TITLE & ID:** Feasibility Study: Lab-on-a-Chip & In-Situ Bioassay Techniques for Rapid Resolution of Ion Signatures for Disturbances of Bio Significance in Streams; CS-1161 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Arthur Stewart / Mr. John G. Smith; Oak Ridge National Laboratory – Oak Ridge, TN

**FY 2000 FUNDS:** $99K

**DESCRIPTION:** Soil disturbances can be expected to generate characteristic "chemical signatures" in runoff water, and thus in the streams, rivers or lakes that are the primary recipients of runoff water from physically disturbed areas. Streams in clear-cut watersheds, for example, have very different ion-export patterns, compared to streams in non-disturbed watersheds. The main objectives of this project are to review the prospects and limits to the ideas that (1) "lab-on-a-chip" technology (or in situ measurement of ions and water-quality properties, such as alkalinity, hardness and conductivity) can be used to decipher relationships between physical disturbances on land and ion balance in surface-runoff, receiving-water systems, and (2) in situ bioassays can be used to reveal biological effects of changes in receiving-system ion balance.

The technical approach will be to explore the feasibility of using automated "lab-on-a-chip" methods to acquire time-series data that relate to several conservative and semi-conservative properties of water known to be diagnostic of biological activity and man-related disturbance. Efforts will be made, using in situ bioassay tests, to link these time-series measurements to biological responses of organisms that respond rapidly to water-quality changes. A screening survey of several streams on or near the Fort Hood Reservation will be conducted based on (1) the availability of calcium-sensitive species of invertebrates that can be used to provide biological responses to calcium-concentration changes in short-term in situ bioassays, and (2) locations that provide a range of disturbance conditions. Additionally, other in situ testing methods will be evaluated.

**BENEFIT:** The expectation is that faster "smart monitoring" techniques that consider chemical and biological variance at shorter-than-conventional time-scales can reduce the monitoring costs and time needed to obtain predictive data, and increase the accuracy of predictions about environmental damage and ecological recovery.

**ACCOMPLISHMENTS:** This is a FY 2000 New Start.

**TRANSITION:** This technology will provide access to real-time data that can be used to model calcium speciation, discern inputs from ion-rich terrestrial areas, and predict biological responses. Radiotelemetry of data obtained by "lab-on-a-chip" analysis techniques is another potential avenue to advance. Remote sensing and reporting methods for environmental media, particularly those that "push the envelop" towards microminiaturization of analytical devices, are useful to DoD and DOE for reasons of environmental security; environmental compliance; environmental clean-up; and better management of DoD lands to minimize onsite environmental damage and offsite migration of pollutants. Such devices would also be of significant interest to National Aeronautics and Space Administration (NASA), Department of the Interior (DOI), the United States Department of Agriculture (USDA) and Environmental Protection Agency (EPA), for related reasons.

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# APPENDIX D
## Pollution Prevention Project Summaries

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## PROJECT SUMMARY

**PROJECT TITLE & ID:** Recycling Propellants in Nonpolluting Supercritical Fluids: Novel Computational Chemistry Models for Predicting Effective Solvents; PP-695

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Betsy Rice; U.S. Army Research Laboratory – Aberdeen Proving Ground, MD

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** Waste solid explosives and gun propellants are destroyed primarily by open pit burning or incineration. Extraction and recycling of the propellant using a non-polluting, inert supercritical fluid (SCF) solvent such as $CO_2$ has economic and environmental advantages. Although the ingredients in composite (nitramine based) propellants are insoluble in $CO_2$, solubility is enhanced when trace amounts of simple polar modifiers are added to the SCF solvent. The objective of this project was to determine the optimal physical conditions and chemical makeup of an effective SCF $CO_2$ solvent with added polar modifier using well-established computational chemistry techniques. The technology developed in this project will have application to nitramine-based explosive and propellant formulations.

**BENEFIT:** The principle benefits include prevention of pollution associated with disposal of Army and Navy explosives and gun propellants and associated reduction of life cycle cost of munitions. Recycling is an alternative to current open burning/incineration of gun propellants which is increasingly restricted.

**ACCOMPLISHMENTS:** The "porting" or "transitioning" of the research-grade software to a user-friendly, black-box suite of computer programs that can be executed on either UNIX or WINDOWS computer platforms was completed. Codes have been benchmarked, and a user's manual has been written. The software allows for the prediction of solubility of RDX in pure $CO_2$ or $CO_2$ modified with one of 37 polar modifier molecules at low concentrations. The software also allows the user to include other polar modifiers that were not incorporated as part of the package submitted.

**TRANSITION:** Results of this effort are being transferred to SERDP's recycling initiative (Project Number PP-660) and other DoD demilitarization and recycling initiative. The User will be supplied with a program package and manual that allows for prediction of solubility of energetic materials in multicomponent SCF $CO_2$. Additionally, two previously submitted manuscripts have been accepted for publication or are in press. One paper is published in the Journal of Physical Chemistry B, Vol. 103, pp. 6783-6790, and the second manuscript is pending publication by Fluid Phase Equilibria. Other manuscripts describing improved models for RDX and TNT solubility calculations in pure $CO_2$, $CO_2$ and polar-modified SF $CO_2$ are being prepared. The solubility of HMX in SF $CO_2$ was investigated and it was observed that, contrary to expectations, HMX solubility was not enhanced by the presence of TNT. This apparent discrepancy between theory and experimental results is being studied.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Solventless Manufacture of Artillery Propellant Using Thermoplastic Elastomer Binder; PP-867

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Larry Merwin; U.S. Naval Air Warfare Center – China Lake, CA

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** Multi-base gun propellant for artillery ammunition creates 0.3 lb of solvent emissions per lb of propellant with an estimated propellant production rate of 3 million lb/yr. The objective of this project was to demonstrate the feasibility of reducing or eliminating the emission of volatile organic compounds (VOC) and solvents associated with the production of gun propellants by using thermoplastic elastomer (TPE) propellants. New reduced-solvent or solvent-less propellant formulations will be developed and evaluated for replacement of current propellants. This project demonstrated at a pilot plant scale, the production of TPE gun propellant by using solvent-less continuous processing.

**BENEFIT:** Once the technology is fully developed and implemented, solvent emissions, including approximately 500,000 lb/yr VOC emissions and 400,000 lb/yr of other solvent emissions (contaminated with explosives), from triple-base gun propellant manufacture can be eliminated. The technology will eliminate scrap propellant by reworking propellant in the manufacturing process. Savings will be achieved through VOC elimination facility modifications and reduced solvent and energy costs in heating drying houses.

**ACCOMPLISHMENTS:** Thiokol produced 500 pounds of BAMO/AMMO/TPE (BAT)-5RDX artillery gun propellant. This propellant was tested in 155-mm howitzers under hot (145° F), cold (-60° F) and ambient (70° F) temperature conditions. The results indicated that the required performance may be achieved through continued improvements in charge design. The mechanical properties of this BAT-5RDX lot are being determined at ARL. Based on the gun firings, the grain is being redesigned.

**TRANSITION:** To leverage the cost of testing and evaluation, this project will be closely coordinated with efforts to develop a propellant charge for the Crusader 155-mm howitzer. Data on new propellants developed under this project will be provided to the Program Executive Officer (PEO) for Field Artillery Systems to choose a new solvent-less propellant formulation to fully develop and qualify for field use. Solvent-less propellant processing technology developed under this project will be transferable to other gun propellant programs. The results of this research titled "TPE Gun Propellant" were presented by the Principal Investigator and team members at the following symposium/conferences: (1) The Army Pollution Prevention Technology Integration Review, July 13-15, 1999, Pocono Manor, PA; (2) The 17th Working Group Meeting on the Synthesis of High Energy Density Materials, September 16-17, 1999, TACOM-ARDEC, Picatinny Arsenal, NJ; and (3) The JOCG Explosives and Propellants Subgroup, September 20-21, 1999, NSWC, Indian Head, MD.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Trapped Vortex Combustor for Gas Turbine Engines; PP-1042

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. W. M. Roquemore; U.S. Air Force Research Laboratory – Wright-Patterson Air Force Base, OH

**FY 2000 FUNDS:** $300K

**DESCRIPTION:** This project will provide the design basis to demonstrate the capability of a trapped vortex combustor (TVC) to reduce pollutant emissions and conserve fuel. The TVC technology is proposed for use in aircraft and in stationary gas turbine engines used on naval vessels. The goals of this project are to demonstrate the feasibility of developing a TVC that will: (1) reduce aircraft pollutant emissions [nitrogen oxides (NOx), volatile organic compounds (VOC), carbon monoxide (CO), and particulate matter (PM)-10] by 60 percent, bringing them significantly below the proposed 1996 Environmental Protection Agency (EPA) regulations; and (2) reduce NOx emissions from a stationary gas turbine by 60 percent, bringing these NOx emissions below the California Resource Board recommendation of 42 ppm and the 1995 EPA regulation for land and marine (L&M) based gas turbine engines burning distillate fuels. A 3% decrease in specific fuel consumption (the fuel mass flow rate required to generate a unit of thrust) is also expected.

The project will develop an optimized trapped vortex design for use in the General Electric (GE) Integrated High Performance Turbine Engine Technology (IHPTET) Phase III prototype gas turbine engine and will evaluate the use of a TVC in stationary gas turbine engines on Naval vessels. Three parts are required to make this new combustor system: a new integrated fuel injector/diffuser, TVC section, and thermal management system. GE will design and test the integrated diffuser and thermal management system. GE and Air Force Research Laboratory (AFRL) will work together to design and incorporate the low emissions TVC portion and will incorporate all three efforts into a final design. The technical approach uses a combined Computational Fluid Dynamics (CFD) design study with an experimental sector rig study to investigate different TV configuration at realistic conditions and with realistic size combustors. TVCs with three different missions will be investigated. The first mission corresponds to a future high performance aircraft that would utilize IHPTET engine technology. The second mission corresponds to that of a conventional aircraft. This mission is included to provide the Air Force with the option of upgrading existing engines to a low emissions, fuel efficient TVC in the future. The third mission corresponds to possible future forward-fit for new purchases of Land/Marine (LM) 2500 engines used aboard Naval vessels.

**BENEFIT:** The benefits depend on the extent to which the technology is implemented. If all existing military aircraft had a TVC, the VOCs for the Air Force and Naval bases could drop by a factor of as much as 10 and the NOx emissions could be reduced by 20 percent to 40 percent depending on the aircraft at the bases. This emissions reduction would permit flight operations and training to continue at current levels with reduced or even eliminated fines. If commercial aircraft also had TVCs, then the environmental and cost impact could improve by a factor of 8. In addition to reducing emissions, the TVC would consume 3% less fuel than the current system, with the concomitant decrease in emissions.

**ACCOMPLISHMENTS:** The following accomplishments were achieved in FY 1999:

- A single cavity TVC was experimentally operated and tested under the same operating conditions as was used for testing of the current double cavity TVC design. Results indicate that the single cavity design is capable of achieving equivalent or superior combustion efficiencies and NOx reductions as compared to the double cavity TVC. Additional work in design of the air distribution system is required. High pressure and high inlet temperature single cavity tests with the 12" sector TVC are being planned. The single cavity TVC would eliminate one of the two cavities in a TVC, reducing its size and cost by approximately 30 percent.

- Modeling studies to investigate the effects of additional cavity air injection for LM2500 use were conducted. Initial indications are that at least a 15% reduction in the NOx formed in the cavities can be achieved.

- The 12" TVC sector was modified to increase the cavity air injection and to reduce the air to the liner cooling jets. The modified combustor will be evaluated at LM2500 conditions starting in January 2000.

- Twenty-one different configurations of the Integrated Diffuser Injector Flameholder (IDIF) were modeled in order to reduce NOx emissions and the number of fuel injectors. Four of the configurations produced the same or even better NOx reductions with half (30 of the 60) of the fuel injectors included in the original design. By cutting the number of TVC fuel injectors in half, the TVC cost will be dramatically reduced. The detailed design for the best swirl jet configuration has been completed and fabrication has started. Testing is planned for March. 2000.

- The Air Force Research Lab and the Department of Energy's Federal Energy Technology Center have agreed to pursue a joint research program to investigate the low NOx capabilities of a Rich-Burn, Quick-Quench, Lean-Burn (RQL) TVC.

**TRANSITION:** Full-scale tests will be performed at GE Aircraft Engines/Allison ADC with the optimized TVC in a full-scale prototype IHPTET. The TVC is targeted for the following products: (1) a new high performance aircraft engine; (2) retrofit for upgrading existing engines; and (3) forward fit of new LM2500 engines for Naval vessels.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Pesticide Reduction through Precision Targeting; PP-1053

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Richard Brenner; Department of Agriculture, Imported Fire Ant & Household Insects Research Unit – Gainesville, FL

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** The Department of Defense (DoD) presently uses approximately 1 million lbs of pesticide active ingredient annually, excluding pesticides used during major deployments. In each of these settings, these pests and disease vectors affect the health of DoD personnel by transmitting pathogens, contaminating foods and surfaces, and producing allergens. The overall goal of this project was to reduce pesticide use and associated risks through the use of precision targeting and comparative risk reduction. This project resulted in the development of a comprehensive, standardized, verifiable, and documentable system for protecting troops, DoD supplies, and DoD facilities from disease vectors and pests in a manner that reduces pesticide use and risk. This novel approach to integrated pest management (IPM) is applicable to three major settings: (1) military deployments and training exercises, where vector-borne diseases, such as malaria, leishmaniasis, dengue, and tick borne illnesses, cause direct loss in troop combat effectiveness; (2) the DoD supply system and supply depots, where pests cause losses to war stocks of military rations and other material such as uniforms and blankets; and (3) military installations, where a wide range of pests cause damage to buildings, structures, and vegetation.

**BENEFIT:** Successful execution of this research will provide standardized procedures for achieving comparative risk reductions associated with the broad scope of disease vectors, pests, pesticides, and pesticide resistant populations in military theaters of operation as well as on military installations. Specific payoffs include reduced use of pesticides by as much as 40-80 percent via a comprehensive, standardized, verifiable, and documentable system, and reduced direct and indirect costs of pesticides.

**ACCOMPLISHMENTS:** The researchers completed the development of the software tool, delivered software and provided instruction to Navy personnel at the Navy Environmental and Preventive Medicine Unit 5 in San Diego. The software was demonstrated, and beta testers learned and practiced the sequences of a precision targeting project from start to finish. Another exercise was conducted at Camp Pendleton with Navy and Marine personnel to demonstrate the use of GPS equipment integrated with aerial photos and building footprints. Beta testers learned how to establish the project and develop real-time GPS themes to collect data as would be necessary for outdoor projects or deployment scenarios. Both military and commercial GPS units were integrated with the customized SERDP software. Defense Logistics Agency (DLA) personnel from northern California attended and simulated a project pertaining to reducing pesticide use in warehousing. A final briefing of the NEPMU5 Commanding Officer was held, and personnel assigned to environmental management of ship operations attended.

Based on successful development and deployment of this research product in a record 4-years time, the project was awarded the SERDP "Project of the Year" Award for FY 1999 at the SERDP Symposium.

A manuscript detailing dengue fever transmission thresholds has been accepted by the American Journal of Tropical Medicine and Hygiene (Focks, et al.).

**TRANSITION:** The researchers are working with the U.S. Army Center for Health Promotion and Prevention Medicine (CHPPM), which has begun a tick management project at Ft. AP Hill, for technology transfer. CHPPM has begun to take the concept of precision targeting to the next stage of sophistication, from mapping of tick distribution and treatment locations to developing an algorithm based on co-variates and expert opinion. This project, conducted entirely by Army entomologists from CHPPM North and CHPPM at Aberdeen, MD, is part of the technology transfer transitioning being conducted and reported to

the Armed Forces Pest Management Board (AFPMB). Refinements continued based on input from U.S. Army CHPPM personnel. They received a second beta version in early September 1999 and field-tested it late in the month at Ft AP Hill. Feedback was wholly positive, and it would appear that all adjustments to integrating GPS, creating data analysis masks, interpolating and contouring data, creating treatment themes, and comparing pre- and post-treatment data for efficacy and pesticide reduction are completed. Refinements in establishing an electronic data management system were made so that data can be ported to and from field operations easily and accurately. The Graphical User Interface (GUI) was finalized so that all case studies and help systems would accurately convey the look and functionality of the system. Help files are now being prepared for the final delivery of product to the AFPMB. An enhanced update wizard has been prepared that ensures software compatibility and proper installation.

Following successful development and testing of this concept, full documentation will be presented to the AFPMB for possible expansion to other pests and DoD operations. The website at which all project software will be available is under construction as a part of the home page to the Imported Fire Ant & Household Insects Research Unit of the USDA-ARS at the Center for Medical, Agricultural, and Veterinary Entomology.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Low VOC Chemical Agent Resistant Coatings (CARC); PP-1056

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Robert Katz; U.S. Army Armament Research, Development, and Engineering Center – Picatinny Arsenal, NJ

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** This project developed a low volatile organic compound (VOC) Chemical Agent Resistant Coating (CARC) system suitable for use on military equipment in which the materials and processes for the reformulation/application, stripping, and disposal are optimized and in compliance with current and anticipated regulatory requirements. The primary focus was to reduce the VOC of the polyurethane topcoat from 3.5 lb/gal to 1.8 lb/gal. Additionally, this CARC will eliminate the hazardous air pollutants (HAP) and toxic solvents used in the current topcoat formulation.

**BENEFIT:** At current annual usage, a CARC targeted to a 1.8 lb/gal VOC limit would save at least 5 million pounds of VOC per year, proportionately reduce photochemical smog generation and avert Notices of Violation (NOV) at user facilities including depots, air logistic centers (ALC), bases, and original equipment manufacturers. VOCs which would be reduced or eliminated include: methyl isobutyl ketone, methyl isoamyl ketone, toluene, xylene, and butyl acetate, all of which are HAPs. The technology developed by this project will also eliminate the need to install emission control devices for approximately twelve facilities for a total cost avoidance of $60 million for equipment installation and $3 million in annual operating costs. By developing one CARC topcoat for use by all the Services, substantial savings will result in procurement and logistics operations.

**ACCOMPLISHMENTS:** After successful development of the new CARC formulation, the FY99 efforts focused on stripping tests using chemicals which have been used recently at various depots. The most recent data acquired in the wheat starch, laser and chemical stripper tests yielded results similar to those obtained from stripping with steel shot, flash jet, plastic media, and garnet. The recent data indicate that the new CARC strips at a rate similar to that of the current CARC topcoat.

**TRANSITION:** The U.S. Army Research Laboratory (ARL) hosted a DoD /User /Supplier CARC Workshop to present plans for technology implementation. Two depots, Letterkenny Army Depot, PA and Anniston Army Depot, AL, will host field demonstrations of the new coatings application under different environmental and seasonal conditions. Subsequently, vehicles will be shipped to various locations for severe field service performance evaluation. Two technical reports by ARL were published: ARL-TR-1950, "Development of Polyurethane Coatings for Military Applications, May, 1999, and ARL-TR-2048, "Water Dispersible Polyurethane Coating Test Protocol", Sept., 1999. Additionally, two papers titled "Low VOC and HAP-free Camouflage Coatings for DoD Applications", and "Development of a Low VOC Chemical Agent Resistant Coating", were presented by the researchers at the 10th Annual International Workshop on Solvent Substitution, Scottsdale, AZ, Sept. 13-16, 1999.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Eliminate Toxic and VOC Constituents from Small Caliber Ammunition; PP-1057

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Kevin Hayes; U.S. Army Armament Research, Development, and Engineering Center – Picatinny Arsenal, NJ

**FY 2000 FUNDS:** $500K

**DESCRIPTION:** The goal of this project is to develop non-toxic small caliber ammunition which will meet U.S. and North Atlantic Treaty Organization (NATO) performance standards for all calibers (5.56 mm, 7.62 mm, 9 mm, .50 caliber). This effort will focus on eliminating toxic components in the projectile core, primer, and manufacturing processes. The proposed solutions will be economical and feasible while meeting all environmental regulatory guidelines and standards over the life cycle of the cartridge.

Projectile core: The approach is to conduct the appropriate environmental studies of candidate projectile core materials to ensure their viability for use in non-toxic projectiles, and provide methods by which the recovery of the material is optimized and release is minimized. Environmental testing will include leaching, corrosion, and biological uptake studies to determine the form, chemistry, mobility, and uptake of unrecoverable materials. These results will provide guidance for optimizing the environmental stability and thus maximizing recovery and recyclability of the next generation of projectile materials. The major areas of concern for projectile core replacement are the terminal ballistic performance (lethality/penetration) and mobility/toxicity of materials. The final candidate must conform to all bio-uptake requirements.

Cartridge primer: This effort will utilize a new class of non-toxic energetic materials called metastable interstitial composites (MIC) as a replacement for current primer materials which include lead styphnate, barium nitrate, and antimony sulfide. A MIC material is an engineered energetic consisting of two or more chemical species that are exothermically reactive with each other. There are three areas of concern for replacement of current primer materials. First, the MIC compounds have never been used in small arms percussion primers. Second, the temperature output from the MIC composition upon ignition must be verified. Third, performance of these materials when subjected to high rates of fire such as in a minigun, must be investigated. A final design configuration will be established and subjected to long-term storage tests.

**BENEFIT:** This project will develop a non-toxic cartridge that will eliminate the environmental and hazardous effects that are associated with current ammunition. It is anticipated that approximately $2.5 million required for waste removal at each outdoor firing range as well as the $100K annual cost for lead contamination monitoring will be eliminated. Furthermore, the 601 indoor National Guard ranges currently closed will no longer require $150K/each in upgrades to become operational, thereby saving $90 million. Lake City Army Ammunition Plant costs will be reduced by $100K per year from elimination of lead sludge treatment. Once the automated MIC process is implemented, a reduction in 15 operating personnel is estimated that will result in a $750K savings annually.

**ACCOMPLISHMENTS:** The first production lot of approximately 897,000 Green Bullet 5.56mm M855 cartridges passed Lot Acceptance Testing at Lake City Army Ammunition Plant on 15 Dec 1999. The ammunition will complete packing and will subsequently be ready for distribution to the field. A contract option for an additional 3 million cores was awarded by TACOM-ARDEC last week and deliveries will begin in March 2000.

Los Alamos National Laboratory (LANL) continued to fabricate M41-style MIC-based primers for pressure-versus-time cartridge tests at the Army Armament Research, Development, and Engineering Center (ARDEC) / Picatinny Arsenal. One hundred primers were manufactured in the best configurations consistent

with the results of the Taguchi experiment. These primers were tested at ARDEC, and the results were consistent with the data obtained from the Taguchi experiment. Based on these results, LANL began manufacturing 500 primers of these configurations to be used for comprehensive testing in "full-up" cartridges in test barrels, weapons, at extreme hot and cold temperatures and in weapon functioning tests. Progress was made at LANL in developing increased production capabilities for MIC reactants. The prototype reactor at LANL was modified to accommodate a continuous powder collection system.

**TRANSITION:** ARDEC, the lead laboratory for the ammunition Single Manager, will work with industry and the Lake City Army Ammunition Plant (LCAAP) to facilitate transition of results into products ready for use in the field.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Elimination of Toxic Materials and Solvents from Solid Propellant Components; PP-1058

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Robert Stanley; U.S. Army Aviation and Missile Command - Huntsville, AL

**FY 2000 FUNDS:** $1050K

**DESCRIPTION:** The overall goal of the "Green Missile" program is to eliminate major sources of toxic/hazardous materials used in solid rocket propulsion systems. The objectives are to: (1) develop lead-free extrudable and castable propellant for minimum smoke systems; (2) develop complete and clean, HCl-free, combustion of propellant; (3) develop solvent-less methods for processing energetic oxidizers; and (4) develop thermoplastic elastomer based inhibitors. The technical risk of this research is that the materials developed may not have the necessary propulsion characteristics.

Lead Elimination: Propellants containing ammonium nitrate (AN) with CL-20 or AN with RDX will be developed further to optimize combustion properties. Combinations of CL-20 and ammonium dinitramide (ADN) will be developed, the chemical and physical properties of their different material forms will be characterized, and their formulation and processing will be evaluated. Formulations containing alternative materials such as bismuth salicylate or bismuth citrate will be evaluated. For extrudable propellants, the filled double base and the extruded composite lead-free alternatives will be scaled-up to larger pilot plant mixers to more fully characterize physical and ballistic properties. Runs of thermoplastic elastomer (TPE) propellant formulations will be transitioned from torque rheometer and small-scale horizontal mixer to the pilot plant twin screw extruder.

HCl Elimination: Research will continue to evaluate ultrafine aluminum (UFAL) and/or ADN propellant compositions using low-solid content and energetic plasticizers to give highly efficient and clean burning propellants while meeting performance requirements. In collaboration with the Air Force Research Lab at Edwards AFB, UFAL will be characterized to determine particle size distribution, particle shape, and surface area. Propellant compositions will be optimized and evaluated.

Clean Oxidizer Processing: The solventless process set up for preparation of molding powders on the 100 gm scale by coating RDX with dioctyl maleate (DOM) using supercritical carbon dioxide will be modified in order to utilize supercritical propane to coat RDX with polyethylene. Solventless production of polyethylene-RDX molding powders will be demonstrated, process conditions will be optimized, and the molding powder will be characterized. The pressed explosive properties of the molding powder will be evaluated. A cost/benefit analysis comparing this process with a solvent-based process and a solvent/liquefied gas non-solvent-based process will be performed.

The existing technology base of the antisolvent comminution process for high energy oxidizers will be further developed and enhanced. Oxidizer recovery will be increased to greater than 99 percent. Continued scaled up testing will be conducted to further evaluate the production of both fine and large oxidizer particles. The technical challenge of generating comminuted CL-20 oxidizer particles in the optimal epsilon crystal polymorph is still being pursued and remains a technical risk.

TPE Development for Solid Rocket Motor Propellant: Three different polymeric inhibitor systems will be evaluated as potential replacements for the baseline cellulosic inhibitor. The candidates are polyphosphazenes, POSS polyurethanes, and POSS norbornenes [POSS= poly(oligosilsesquioxane)]. Tasks include production of the polymeric candidates, characterization of the physical properties of the polymers, performance of adhesion tests of the candidate polymers with motor propellant candidates from Naval Surface Warfare Center - Indian Head (NSWC-IH), selection of the best candidate and scale-up synthesis for evaluation.

**BENEFIT:** Immediate benefits from the research are: (1) a lead-free formulation for HELLFIRE and the Tri-Service 2.75 inch rocket, solving 95% of the current lead emission problems; (2) an HCl-free formulation for MLRS, eliminating HCl emissions that can endanger ground forces and damage ground equipment; (3) a solventless energetic oxidizer process for HELLFIRE, a solution for 60% of the ADN/CL-20 systems and a new process for the manufacture of polyethylene/RDX molding powders and (4) a solventless method for application of inhibitor. With technology transfer to similar systems, the potential overall cost savings from the research are $1.5M from lead elimination and $3M with solvent elimination/minimization.

**ACCOMPLISHMENTS:** Lead Elimination: A high performance non-lead propellant was successfully tested in a 2.75 inch Rocket motor case. Further testing will be performed over a temperature range of -40°F to 140°F. Development of ADN and ADN/CL-20 mixtures continued. Their burn rate data were encouraging, but further work is necessary to improve the mechanical properties of these propellants. Investigation of the use of two non-leaded catalyst systems (copper B-resorcylate and a ternary system of bismuth salicylate, copper salicylate and copper B-resorcylate) continued.

HCl Elimination: An energetic propellant has been devised which produces no HCl or other halogen acids upon combustion. A baseline composition is being characterized which contains UFAL, spherical Al, ADN, PAO, and BTTN. Evaluation and characterization of UFAL fuels continued.

Clean Oxidizer Processing: A series of anti-solvent comminution experiments were conducted to generate several pounds of recrystallized RDX oxidizer that had been previously recovered from obsolete Army rocket motors. Achievements included (1) the comminution of high purity RDX from crude recovery products, (2) the generation of both small and large particle sizes of RDX oxidizer, and (3) the recovery and recycling of the processing solvent. Greater than 99 percent of the initial RDX was recovered as comminuted particles. A process to generate large comminuted RDX particles in the required 100-micron regime was successfully developed. As a consequence, a multi-step process was developed that would generate a multi-modal blend of both small and large comminuted RDX particles.

**TRANSITION:** Program Managers/Program Executive Officers for HELLFIRE, Tri-Service 2.25 inch rocket, and TITAN are prepared to endorse this technology when successfully demonstrated.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Next Generation Fire Suppression Technology Program; PP-1059

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Richard Gann; National Institute of Standards and Technology, Building and Fire Research Laboratory – Gaithersburg, MD

**FY 2000 FUNDS:** $3000K

**DESCRIPTION:** Halon 1301, the predominant and critical total flooding fire suppressant installed in weapons systems, is no longer in production due to its deleterious effect on stratospheric ozone. The objective of this program is to develop and demonstrate, by 2004, environmentally acceptable and user-safe processes, techniques and fluids that meet the operational requirements currently satisfied by Halon 1301 systems in aircraft, ships, land combat vehicles, and critical mission support facilities. The results will be specifically applicable to fielded weapons systems and will provide dual use fire suppression technologies for preserving both life and operational assets. This effort leverages prior SERDP-funded research and the Research Development, Test, and Evaluation (RDT&E) infrastructure created under the ongoing Department of Defense's (DoD's) near-term research program.

The research approach consists of six parallel Technical Thrusts, closely integrated to achieve specific milestones within an 8-year time frame. This approach was developed collaboratively by government, industry, and academic experts in fire science, the contributing technical disciplines, instrumentation, testing, and Halon 1301-protected weapon systems. Following are the six Technical Thrusts, which embody 24 separate research elements.

- Risk Assessment and Selection Methodology develops a process for choosing among alternative technologies by applying modern decision-making concepts.
- Fire Suppression Principles establish the mechanisms of flame extinguishment using detailed experimental studies and computational models leading to new approaches for fire control.
- Technology Testing Methodologies select, adapt, and develop test methods and instrumentation to obtain data on the effectiveness and properties of new suppression approaches.
- New Suppression Concepts define new ideas for fire suppression based on chemical and physical principles.
- Emerging Technology Advancement accelerates a variety of processes, techniques, and fluids that are currently under development.
- Suppression Optimization develops the knowledge to obtain the highest efficiency of each candidate technology.

This is a "living" program, representing the best current thinking for achievement of the objective, yet adaptable as the knowledge base grows. There are always risks in such an undertaking. For instance, there might be no chemicals that perform well for all the desired properties; no new fire suppression technologies might emerge; optimization principles might not improve mediocre approaches sufficiently; and lab-scale measures might not adequately predict real-scale performance. This research is designed to provide the scientific understanding to maximize the likelihood of overcoming risk factors.

**BENEFIT:** The outcome of this program will be demonstrated alternatives to Halon 1301. This will enable DoD weapon system managers to removing their dependence on a key ozone-depleting substance while minimizing fiscal and operation barriers to implementation.

**ACCOMPLISHMENTS:** Accomplishments achieved in FY99 include:

- Assembly of the chemical kinetic mechanism to treat the inhibition of Mn-containing species.
- Analysis of possible variations of rate constants suggests that it is possible that Mn - containing agents could be as efficient as Fe(CO)5 at 100 ppm of additive.
- Design, construction, and demonstration of a counterflow burner for flame structure studies and for flame modeling comparison.
- Submittal of the manuscript entitled "Factors Influencing Chemical Flame Suppression" to Combustion and Flame.
- Measurement of the behavior of various sizes of water droplets in propane/air and methane/air counterflow non-premixed flames at several strain rates. For mildly strained propane/air flames, 30 micron diameter droplets are as efficient as smaller droplets at flame extinction, whereas 42 micron and larger droplets were much less efficient.
- Completion of the Focal Plane Array Imaging for different mass loading and PMMA thickness. The results have been submitted to the Journal of Fire Safety. The integration of optical system for surface temperature measurements has been completed.
- Completion of extinction experiments with JP-8 pool fires using both halon 1301 and HFC-125 fire suppressants. Both exhibited behavior to that observed in previous extinction tests.
- Completion of the physiological model framework for lung and cardiovascular system and adaptation of the physiological model to short term inhalation scenarios. The protocol for the genotoxicity screen of volatile chemicals was completed.
- Completion of detailed chemical kinetic modeling of extinguishment of opposed-flow laminar diffusion flames of methane burning in air and thermal-agent mixtures.
- Development of a model of surface cooling for use in identifying liquid agents which should be particularly effective for cooling burning fuel surfaces.
- Submittal of a paper on the experimental studies of the fluoronated ethers and a paper on the ab initio studies of CH2Br2 to the Journal of Physical Chemistry.

**TRANSITION:** This is an eight-year, comprehensive research and development (science and technology) effort with leveraged funding from all DoD Services, industry, and academia. Successful sub-projects will be further developed within this program. "Spin offs" to various weapons systems development programs are anticipated.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Tri-Service "Green" Gun Barrel - A Physical Vapor Deposition for the Application of Environmentally Safe Coatings for Gun Barrel Bore Protection; PP-1074

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. John Vasilakis; U.S. Army, Benet Laboratories – Watervliet Arsenal, NY

**FY 2000 FUNDS:** $850K

**DESCRIPTION:** This project will develop an innovative dry (non-aqueous) process for the deposition of chromium or other materials equally suited to the bore protection of a gun barrel to replace the aqueous electrodeposition process. This novel process is called the Cylindrical Magnetron Sputtering Process (CMS). The project will result in an advanced technology demonstration addressing specific Army, Navy, and Air Force requirements in the plating of the Medium Caliber Barrels. Moreover, it will show that the work can be spun off to Large Caliber Gun Barrels and other applications including cylinders for recoiling mechanisms, aircraft landing gear, the oil processing industry, the power generation industry, and the mining and exploration industry.

CMS is a dry, environmentally clean technology capable of depositing chromium on gun tubes. It also has the flexibility to deposit other refractory metals and their alloys as well as being able to tailor the coating properties through the deposition thickness. Although the focus is on chromium, the deposition of alternate materials, such as tantalum, which will eliminate environmental problems as well as provide improved bore protection, will be evaluated. If chromium were deposited, environmental problems can still exist because a "consumable" chromium target would have to be made, most likely, by the same electrodeposition process that this project seeks to eliminate. Initial efforts will focus on developing the facility for investigating a single medium caliber size and the parameters required for depositing a well-adhered, uniformly-coated tubular section. Once established, the facility will be sized to accept the different caliber gun tubes provided by the tri-Service partners. These will be returned to the partners for firing tests. Leveraged support is through universities, other government agencies, and industries. Some of this support is through additional funds while other support is through exchange of services. Where necessary, Cooperative Research and Development Agreements (CRADAs) will be developed if non-existent.

**BENEFITS:** Current weapon systems and those currently being developed or planned will have gun tubes with chromium deposited on their interior/bore surface to protect the bore surface from the hot propellant gases and the mechanical effects of the projectile. Current technology relies on an wet process known as aqueous electrodeposition. The chromic acid used in the deposition process contains hexavalent chrome, a known carcinogen that is extremely expensive to manage and dispose. For example, in FY95 for large caliber barrels, the cost of wastewater treatment and sludge removal was $2.3M. This program will develop a dry, environmentally clean replacement process for aqueous electrodeposition chromium plating facilities.

**ACCOMPLISHMENTS:** Several tests to investigate the uniformity of the plasma, the material phase of the deposited tantalum and the effect of different inert sputtering gases were conducted using the laboratory 25mm cylindrical magnetron sputtering (CMS) demonstrator. The diffusers at the specimen ends were successfully redesigned to enable relatively uniform plasma throughout the entire length of the specimen. Tests with argon as the inert sputtering gas resulted in successful deposition of the alpha tanatalum phase to a thickness of one mil. Some additional positive effects were noted with tests using krypton in place of argon, but the specimen has not yet been sectioned for analysis.

A novel technique was developed for measuring the residual stress in sputtered coating using Laser Scanning Confocal Microscopy. The use of pulse laser heating to apply thermal shock to a sputtered sample has been developed. Work with the vented combustor and the plasma and deposition modeling programs continued.

The M242 Bushmaster demonstrator is approximately 75 percent complete. It is expected to start commissioning tests with CMS on 55" long Bushmaster gun barrel sections in January, 2000.

**TRANSITION:** There is Tri-Service support for the program and typical medium caliber barrels from each of the Services will be coated with the new process and test fired at each of their respective facilities. The program is also heavily leveraged with others from not only the environmental area, but also from gun barrel wear and erosion areas. Industry has provided information to the program regarding environmental costs and has indicated interest in applying the technology after development.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Replacement of Non-Toxic Sealants for Standard Chromated Sealants; PP-1075

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Alan J. Fletcher; U.S. Air Force Research Laboratory – Wright Patterson Air Force Base, OH

**FY 2000 FUNDS:** $390K

**DESCRIPTION:** The objective of this work is to formulate and test candidate non-chromated sealants that will provide equivalent or improved properties as compared to the existing chromated sealants while meeting the requirements of MIL-S-81733C. Additional goal is to reduce the volatile organic compound (VOC) content of the materials by 65 percent.

Sealants are required in aircraft systems and on weapons to provide protection against corrosion, prevent moisture entry, provide a fuel barrier, and provide electrical insulation. Traditionally, sealants use chromium as the primary corrosion inhibiting substance. Chromium has been designated as hazardous and is targeted for elimination in order to comply with either current or pending Occupational Safety and Health Administration (OSHA) requirements. Most sealants also contain VOCs such as methyl ethyl ketone (MEK) and toluene. Under this project team's guidance, a chromate-free corrosion inhibiting sealant has been developed, tested and transitioned to the field. A new polymer has been developed that is characterized by properties beneficial to corrosion-inhibiting sealants: rapid cure times without a reduction in work life; a pleasant odor; excellent rheological properties; excellent cure at low temperatures; and high solvent resistance. The proposed work is directed towards use of this new polymer to formulate corrosion inhibiting sealants for all the types and classes of MIL-S-81733.

The approach encompasses the following tasks:

***Polymer Selection and Optimization:*** This task will select, develop and optimize the base polymer system to be used for formulation development. The end result of the task will be a base polymer system that can be used to formulate non-chromated corrosion inhibiting sealants.

***Selection of Curing Agents:*** This task will research, develop and formulate curing agents for the base polymers systems selected. A contract will be awarded to the sealant manufacture from Task 1 to research and develop curing agents for the base polymers systems selected. These curing agents will be non-chrome and minimum VOC compounds that provide the best curing mechanism.

***Selection of Corrosion Inhibitor:*** This task will research, develop, test and optimize non-chromated corrosion inhibitors. A contract will be awarded to sealant manufacturers that have successfully completed Task 2 to research, develop and optimize corrosion inhibitors for their sealant system.

***Selection of Sealant Systems:*** The requirement for each type and class of product will be reviewed by the team and the selection of one sealant system will be made for formulation into a sealant material that will meet the requirements for the intended use of each type and class of material.

***Formulation of Sealant Compounds:*** This task will formulate sealant compounds needed to replace two of the types and classes found in MIL-S-81733.

***Formulation Testing:*** Laboratory or pilot plant batches of each formulation will be tested for the critical requirements of type and class or sealant. Material samples will be provided by the sealant manufacturers to the Air Force Research Laboratory, the Naval Air Warfare Center, and the Army Research Laboratory. These laboratories will test the formulations to the critical requirements of each service.

***Candidate Optimization:*** This task will optimize the promising formulations and will include optimization for ease of application, pilot plant manufacturing and testing, and scaled-up to production batches.

***QPL Testing:*** This task will perform qualification testing on new formulations. Once a formulation has been finalized, qualification testing will be conducted on production batches of the material. MIL-S-81733 and AMS 3265 will be used for qualification test procedures.

**BENEFIT:** The benefits of this project are: (1) reduced use of hexavalent chromium and VOCs; (2) development of longer shelf-life sealant formulations; (3) development of primerless sealant formulations; and (4) expansion of technology enabling the replacement of other chromated sealants.

**ACCOMPLISHMENTS:** The following accomplishments were achieved in FY99:

- Screening of representative samples from at least ten basic, thiol terminated P-3.1 polymer systems is underway to determine initial and cured Tg, flexibility, basic chemical resistance properties, thermal resistance properties, and conformance to EPA-17 and AFMC-24 requirements to support development of the base compound.

- Development of a curing agent: based upon screening studies previously conducted by Courtaulds Aerospace, the best work life to cure ratio is obtained by using mixtures of epoxy resins for the curing agent. Experiments are on-going to evaluate a variety of epoxy resin-curing agents with the goal of identifying the best type, functionality, and blend for the base polymers referred to in Task 1.

- Development of a corrosion-inhibiting agent: based upon work previously conducted by Courtaulds Aerospace, corrosion-inhibiting agents will be phosphate salts and will be as effective as chromium at deterring the onset of corrosion. Several inhibitor candidates are being evaluated in screening experiments.

- Study of the changes necessary to adapt the PARIS II solvent design software to the design of solvents for use with the new sealants.

**TRANSITION:** MIL-S-81733 will be revised and implemented throughout DoD to incorporate the new non-chromated sealant compound while meeting all the other specification requirements.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Non-Polluting Composites for Remanufacturing and Repair for Military Applications; PP-1109

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Bruce Fink; U.S. Army Research Laboratory – Aberdeen Proving Ground, MD

**FY 2000 FUNDS:** $1000K

**DESCRIPTION:** The technical objective is to research, develop, and demonstrate a unique, affordable, environmentally friendly family of polymer-matrix composite (PMC) manufacturing and repair technologies for stand-alone repair of current, soon-to-be-fielded, and future DoD structures. Repair concepts and technologies will be demonstrated on DoD-specific problems, including the design and implementation of a non-autoclave repair procedure for the Army's complex integrated polymer composite lightweight armor designs used on the Composite Armored Vehicle and the Crusader Self-Propelled Howitzer (SPH); the development, demonstration, and documentation of a repair-friendly processing method for the remanufacture of the Navy's FY02+ fielding of the Advanced Enclosure Mast Sensor System (AEMSS) including multifunctional material development; and the development of several advanced concepts for non-autoclave manufacture and repair of thin composite skins for aircraft and Army rotorcraft.

This program investigates a variety of novel composite processing and cure methods, including vacuum-assisted resin transfer molding (VARTM), the multi-resin co-injection process, electromagnetic PMC curing techniques, and novel portable radiation (ultraviolet and electron beam) cure techniques to solve pollution problems in composites re-manufacturing and repair for military applications. A key to success is tight control over temperature during processing, reducing residual stresses and providing a consistent glass transition temperature (Tg) and consistent mechanical properties using recently invented composite manufacturing techniques and optimizing them for repair of complex DoD PMC structures.

**BENEFIT:** This program will create technologies that enable out-of-autoclave processing as well as reduction of emissions from adhesive bonding operations. Used in tandem, these techniques can substantially reduce pollutants and waste in composite repair and remanufacturing. These technologies offer the additional benefit of significantly decreasing the need for recycling scrap and waste materials by enabling efficient material use and reducing the number of processing steps required for the manufacture of multi-functional PMC components (e.g., Crusader and AEMSS) by up to 80 percent. In AEMSS alone, cost savings in excess of $10M over the next 6-7 years are anticipated. This work will have significant 'buy-out' effects on the following requirements:

- Hazardous materials substitution - substituting 100+ tons/yr. of thermoset adhesive on AEMSS through the co-injection process.
- Minimization of hazardous emissions - vacuum-bag repair technologies to control and minimize hazardous effluents and alternatives to the use of adhesives in composite structure manufacturing.
- Reduction of waste and environmentally friendly composites manufacturing - significant reduction in scrap (80 percent) in large-scale manufacturing for DoD applications such as AEMSS and Composite Armored Vehicle (CAV).

Specific benefits include:

- Unlimited shelf life and elimination of associated waste.

- Reduced-pollutant manufacturing and repair technologies enabled by new materials and curing methods.

- Significant reduction in manufacturing waste and emissions for multi-functional composite structures.

- Potential compliance fix for more-stringent processing-emissions standards.

- Quantification of environmental benefits of nonautoclave, reduced-part-count, low-emission technologies.

**ACCOMPLISHMENTS:** E-beam prepreg has been successfully reformulated to be amenable to processing and hand lay-up, followed by debulking for shipment to e-beam cure facility. The new prepreg is still not optimized for toughness under e-beam cure, but the handling of the material will no longer inhibit attempts to evaluate new formulations with improved performance. Additionally, Induction susceptor particles for inclusion in adhesives used in field repair of thick-section composites have been obtained. The characterization and evaluation of performance of these materials is being initiated.

**TRANSITION:** Systems of interest for the application of these novel manufacturing/repair methods and for specific demonstration of the technologies during this program include Army helicopter blade repair with the new Aviation and Missile Command and CCAD; the Navy's mast enclosure redesign, remanufacture, and repair procedure development with the Naval Surface Warfare Center; and Navy/Air Force aircraft skin non-autoclave manufacture and repair through Northrop Grumman and Science Research Lab.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Genetic Enhancement of an Anti-Freeze Protein for Use as a Substitute for Ethylene Glycol for Aircraft Deicing; PP-1110

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. John Henry; Aspen Systems, Inc. – Marlborough, MA

**FY 2000 FUNDS:** $279K

**DESCRIPTION:** Traditional anti-icing/deicing agents are either propylene or ethylene glycol. These agents result in excessive biological oxygen demand (BOD) loading and are toxic to humans, mammals and aquatic species. The clean-up of sites contaminated with these deicers is expensive. For example, at Griffith AFB, NY, the use of glycols as a deicing fluid for aircraft has resulted in ground-water cleanup programs costing over $8.2M. An Air Force policy has been issued banning future purchase of ethylene glycol. The Environmental Protection Agency (EPA) has recently passed regulations that require the construction of on-site collection and treatment facilities for spent deicing chemicals. Under these regulations, waste deicing fluid runoff will be classified as a non-storm water discharge which must have a low BOD and an individual permit if the BOD cannot be eliminated.

This project proposes to develop deicing/anti-icing agents from antifreeze proteins characterized by a BOD substantially lower than the current agents. Initial research has indicated that *Dendriodes canadensis,* a protein found in insects, produces a freezing point depression that is 300 to 500 times the predicted value based on its molal concentration due to non-colligative properties. This project proposes to genetically alter the *Dendriodes canadensis* antifreeze protein (D. can. AFP) gene in order to enhance its freezing point depression capabilities and increase its ability to function as a deicing/anti-icing agent.

**BENEFIT:** Development and use of a deicing/anti-icing agent that is non-toxic and characterized by a low BOD should reduce the costs of the management of deicing/anti-icing operations and minimize the potential environmental impacts from discharge of untreated deicing/anti-icing wastewater to aquatic systems.

**ACCOMPLISHMENTS:** FY 1999 accomplishments include: the cloning of the mutant D. Can. AFP genes into the yeast Pichia pastoris; confirmation of this cloning by PCR analysis; and the expression of an immunoreactive protein that is secreted into the media which confirms the presence of an AFP.

**TRANSITION:** All Services and the commercial airline industry will be apprised of initial results. Successful candidates may be further tested by Service programs.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Environmentally Advantaged Substitutes for Ethylene Glycol for Aircraft Ice Control; PP-1111

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Ms. Carolyn Westmark; Foster-Miller, Inc. – Waltham, MA

**FY 2000 FUNDS:** $693K

**DESCRIPTION:** The technical objective of this program is to develop a high performance, environmentally benign aircraft anti-icing fluid which can be safely released to the environment without capture, control, and post-treatment of the runoff. Specific objectives are to: (1) develop a molecular modeling approach which allows for prediction of non-Newtonian viscosity behavior of materials based on their chemical structure; (2) develop a non-toxic, non-Newtonian thickening agent with enhanced performance capabilities for anti-icing fluids, particularly extended holdover times; (3) select low environmental impact additives for performance enhancement; (4) demonstrate that the anti-icer formulations are compatible with military aircraft materials and weapons systems; (5) demonstrate the ability of the anti-icing formulations to prevent ice formation for extended periods of time in simulated adverse weather environments; (6) develop encapsulated enzyme additives which exhibit controlled release properties and actively degrade the anti-icer formulation at reduced temperatures; (7) predict the water quality impact of new anti-icer formulations at actual airfield sites using computer modeling and laboratory analysis of key environmental parameters; (8) determine any potential health/safety risks of anti-icing formulations; and (9) develop cost-effective anti-icing formulations by screening out excessively costly materials throughout the testing program. The most promising freezing point depressants from an earlier Air Force funded Small Business Innovation Research (SBIR) Phase I program will be used as a basis for anti-icer formulations.

The Foster-Miller strategy to develop environmentally advantaged aircraft ice control materials involves three key elements: (1) identification of ice control material formulations which are inherently less damaging to the environment than current formulations; (2) development of efficient, high performance fluids which require less material to accomplish the objective of protecting aircraft surfaces from ice accretion; and (3) development of "self-remediating fluids" which degrade to less harmful products prior to entering the ecosystem by means of a triggerable reaction. Foster-Miller is already pursuing the development of inherently environmentally advantaged freezing point depressants (FPD) in a U.S. Air Force Laboratory sponsored SBIR program. This SERDP sponsored project focuses on the development of anti-icing fluids, which will incorporate the FPDs developed under the SBIR program.

**BENEFIT:** The project benefits include: (1) a drop-in, fully characterized, environmentally advantaged replacement for ethylene and propylene glycol based aircraft deicing materials; (2) elimination of the cost of capture/treatment of effluent from aircraft deicing processes; (3) reduction of material cost for aircraft deicing processes (since high efficiency fluids require less material usage); and (4) increased flight safety and mission readiness. Additionally, this project will provide a model for non-Newtonian viscosity prediction based on the chemical structure of compounds, a self-remediating anti-icing fluid formulation, and a model for predicting the impact of changes in ice control material formulation on runoff water quality at actual airfields.

**ACCOMPLISHMENTS:** Eight anti-icing formulations, two freezing point depressants (ethylene dioxyethanol and glycerol) and four thickeners (xanthan and welan gums, modified clays, and some combinations of each) were selected for Tier 1 testing. Testing indicated that the rheological properties of several of these formulations closely approximated commercially available Type IV anti-icing fluid. Tier 1 immersion corrosion testing was completed on FPDs. Ethylene dioxyethanol and glycerol passed the immersion corrosion testing requirements. Wetting (contact angle) tests on candidate FPDs indicated that the formulation will require surfactants to enhance wetting of the aircraft surface.

The propylene glycol (PG) and glycerol degrading enzymes appear to have a lifetime of about 8 days. The PG degrading activity of a purified enzyme extract increased by a factor of ten over the activity of a crude enzyme extract. The PG degrading enzyme was found not to be inhibitory to active biofilms found in waste treatment systems. A water quality impact analysis showed the range of enzyme-assisted decay rates that would represent significant benefits to the management of aircraft deicing fluid runoff in airports.

**TRANSITION:** All Services and the commercial airline industry will be apprised of initial results. Successful candidates may be further tested by Service programs.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Recycle and Reuse of Industrial Rags Using Liquid $CO_2$ and Surfactant Additives as a Cleaning Agent; PP-1112

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Charles H. Darvin; Environmental Protection Agency, National Risk Management Research Laboratory – Research Triangle Park, NC

**FY 1999 COMPLETED PROJECT**

**DESCRIPTION:** The technical objectives of this project was to develop, demonstrate, and evaluate a liquid carbon dioxide ($LCO_2$) fabric cleaning technology for application to the cleaning of DoD generated hazardous cleaning rags. The most promising candidate technology to accomplish this objective is the use of liquid carbon dioxide ($LCO_2$) with surfactant additives.

**BENEFIT:** $LCO_2$ has no associated environmental impacts and few safety concerns. Unlike conventional cleaning technologies, $LCO_2$ is non-hazardous, non-flammable, non-ozone-depleting, and non-toxic. A system using $LCO_2$ is expected to be less destructive to fabrics. Successful removal of hazardous contaminants from cleaning rags will allow recycling of the rags and will eliminate rags as a source of hazardous waste pollution from DoD and related facilities.

**ACCOMPLISHMENTS:** Some preliminary cleaning activity was conducted which indicated the viability of the process. Processing of contaminated rag samples yielded 98 percent removal of the contaminant. In August, 1999 the SERDP program office directed that all FY 99 funded work cease and that remaining FY 99 funds be returned. $242K of the $307K provided for FY 99 is being returned back to OSD Comptroller. The remaining funds were expended prior to the directive. Work funded with FY 98 funds will continue to complete proof of concept research. Work will not proceed up to the point of hardware fabrication.

**TRANSITION:** The military Services will be apprised of initial results.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Sol-Gel Technology for Low VOC, Non-Chromated Adhesive & Sealant Applications; PP-1113

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. James Mazza; U.S. Air Force Research Laboratory – Wright Patterson Air Force Base, OH

**FY 2000 FUNDS:** $1200K

**DESCRIPTION:** The primary objective of this project is to develop and transition to the Department of Defense (DoD) and other organizations processes that eliminate the volatile organic compounds (VOC), chromates, and strong acids typically found in the metal surface treatment and priming steps conducted prior to application of adhesives and/or sealants. Secondary objectives are the reduction of hazardous wastewater streams associated with current processes and improved performance compared to these processes.

This project will develop, evaluate, and field demonstrate nonchromated, zero VOC sol-gel processes for adhesive and sealant applications. The sol-gel processes developed will replace the current approaches that are high-VOC and/or chromates. They will also eliminate the current use of strong acids and reduce the waste streams associated with the existing processes. This project will build on recent work using sol-gel technology to deposit thin organic-inorganic coatings on metal surfaces to develop good adhesion between the metal and subsequently-applied polymers (primer, adhesive, or sealant) via covalent chemical bonding. A main feature of the effort is the extensive leveraging of previous, ongoing, and proposed research.

This project is divided into following four tasks (three adhesive bonding and one sealant adhesion promoter/primer):

- Find an environmentally friendly pretreatment/primer system that can be implemented in the near term by optimizing a sol-gel surface preparation that is compatible with experimental waterborne adhesive bond primers. This will be accomplished by sol chemistry optimization and by developing application procedures with emphasis on the surface activation drying/cure steps. Epoxy adhesives will be the primary focus, although polyamides may also be evaluated for titanium.

- Develop a one-step process that combines the adhesive primer and sol-gel surface treatment into one consolidated interfacial layer. Findings regarding the important process variables identified in Task 1, such as surface activation for the various metal alloys, will be used to develop an application procedure. This approach will eliminate the need for a separate primer step.

- Evaluate the sol/primer mixtures of Task 2 as traditional adhesive primers.

- Leverage the sol-gel work for adhesive bonding to develop adhesion promoters for sealant operations. The highest priority area will be replacing the high-VOC primers used with silicone sealants with a zero-VOC sol-gel alternative. A second priority will be to develop a universal adhesion promoter for polysulfide and polythioether sealants to promote adhesion between these sealants and various substrates as well as adhesion between the two sealant types.

**BENEFIT:** Development of new non-chromated, zero-VOC adhesive and sealant surface preparation and primer technologies will have a major impact on both cost and performance of military and commercial aircraft. Eliminating VOCs and chromates from these processes will result in considerable cost savings due to avoiding the need for hard controls and/or fines for non-compliance. At the Naval Aviation Depot (NADEP) North Island alone, the installation of VOC-control equipment for these processes is expected to cost $15M and the installation of chromate control equipment is expected to cost $2-3M, with operation costs of approximately $250K per piece of equipment annually. However, the majority of repairs at NADEP North

Island are conducted on aircraft; thus, a mandate for hard controls will incur additional costs for removal of parts and increased aircraft downtime. Consideration of cost savings from other NADEPs, U.S. Air Force air logistics centers (ALC), Army depots, and commercial usage will multiply these cost avoidance figures many-fold.

**ACCOMPLISHMENTS:** The sol-gel surface preparation process was demonstrated in September 1999 at the Cherry Point Navy Aviation Depot. The demonstration showed the need to further refine the process by adding additional details to the step-by-step procedures.

- Significant processing parameters as well as key interactions were identified for nylon abrasive pad surface activation techniques for 2024-T3 and 7075-T6 aluminum.

- Processes have been optimized for brush spray and mist application of the sol-gel solution.

- Wet grit blasting surface activation has been demonstrated to be as good as dry grit blasting on titanium

- One-year-old sol-gel kits successfully demonstrated performance equal to fresh formulations. This allows users to procure this surface preparation and store it for up to a year without concern for performance.

- Sol-gel has been successfully demonstrated on clad aluminum. There was initial concern that the coating would degrade the wedge crack test performance. This has not been the case. Therefore, this result could expand the potential applications for sol-gel surface preparation.

- Co-curing the primer with paste adhesives has demonstrated improved performance. This is the first step to enable the user community to apply this surface preparation with paste adhesive.

- The Army Armaments Research, Development, and Engineering Center has developed a preliminary specification for sol-gel applications on stainless steel.

- One hybrid (one-step) chemistry approach, the nanocomposite coating approach based on Chemat Technology's chemistry, has been downselected from the program. Because this approach was not yielding the long-term durability performance (wedge test) desired, additional approaches will be evaluated until a decision is made regarding hybrid development at the end of the next quarter.

- Initial sealant testing indicates that the PR 1750 sealant appears to perform well with Boegel II. Good peel strength results were obtained.

**TRANSITION:** Further testing at NADEPs, ALCs, and Army depots is anticipated after initial successes are achieved.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Visual Cleaning Performance Indicators for Cleaning Verification; PP-1117

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Bruce Monzyk; Battelle – Columbus, OH

**FY 2000 FUNDS:** $516K

**DESCRIPTION:** The visual cleaning performance indicators (VCPI) are a combination of intense dyes and coupling agents (CA) that selectively attach to target contaminants on surfaces cleaned in Department of Defense (DoD) and Department of Energy (DOE) operations. This innovative technology promises to provide a widely-applicable, real-time, low-cost, quantitative/qualitative cleaning process monitoring technique. The implementation of such a technique will reduce hazardous and non-hazardous waste and processing cost by avoiding excessive as well as inadequate cleaning and by enhancing implementation of environmentally friendly cleaning alternatives.

The project consists of three tasks that will be carried out by Battelle in collaboration with Air Force Research Laboratory and Naval Surface Warfare Center-Carderock. In Task 1, the DoD partners will help identify target contaminants for large surface cleaning. Battelle will then select commercially-available CAs and dyes, that can attach to the target contaminants, using known science and with input from DoD partners on material compatibility. The Task 2 consists of feasibility testing of the VCPI concept. The DoD partners will prepare coupons for testing and Battelle will source the contaminant CAs and dyes. In the Task 3, Battelle will clean the VCPI-treated soiled coupons to demonstrate a relationship between color intensity and residual contaminant level. The DoD partners on the other hand will perform application-specific cleaning to determine whether VCPI components are compatible with DoD cleaning operations and materials of construction.

**BENEFIT:** The VCPI technique is expected to be a simple, real-time, and cost effective technique which can help achieve pollution prevention in DoD/DOE cleaning operations by avoiding overcleaning and inadequate cleaning. The cost savings thus realized can be very significant as the current cost of cleaning is high (e.g., $2500/wash for C-130 aircraft and about $22.5M spent in 1990 by USAF to clean and inspect aircraft). The technique appears suitable for a variety of regular and irregular as well as large or small cleaning surfaces.

**ACCOMPLISHMENTS:** Six candidate VCPI test systems were selected. The three forefront candidates are Oil Red O for hydrophobic contaminants, Food Blue No. 2 for water soluble corrosive salt residuals, and Alizarin for corrosion products. Three other CA-dye chemicals were selected as backup candidates. The VCPI concept was demonstrated for the first time to possess the necessary sensitivity to visually observe commercially important levels of contamination using MIL spec lube oil applied to painted and unpainted Al 2024 test panels with and without Oil Red O dye. Similar testing was performed on Al 2024 panels which were heavily and lightly corroded using an Alizarin-based VCPI system. These tests are at the qualitative pre-screening stage.

**TRANSITION:** At the conclusion of this project, Battelle plans to work with DoD/DOE organizations to field test the technique, specifically for aircraft cleaning (Oklahoma City - Air Logistics Center), application of adhesives and painting of shipboard surfaces (Naval Sea Systems Command), and application to critical cleaning for weapons manufacture and demilitarization (DOE, Pantex Plant).

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Supercritical Fluid Spray Application Process for Adhesives and Primers; PP-1118

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Marc Donohue; Johns Hopkins University – Baltimore, MD

**FY 2000 FUNDS:** $386K

**DESCRIPTION:** The objective of this project is to develop or identify low/no-VOC (volatile organic compound), non-structural adhesives to substitute for the current high-VOC, non-structural adhesives used in military applications. It is estimated that 8.5 billion pounds of synthetic polymer adhesives are used annually, of which approximately 55 percent are VOCs. While the total DoD usage is not known, it is estimated that approximately 173,000 pounds of VOCs are released annually by Air Force aircraft operations. VOCs commonly used in applying adhesives include aromatics (e.g., toluene), ketones (e.g., acetone, methyl ethyl ketone), and others (e.g.,methanol, chloroform) which negatively impact worker health and safety, adversely affect environmental standards, are ozone depleting, and result in increased hazardous material management costs including permitting and installation of sophisticated emission control equipment.

Conceptually, the UNICARB process is straightforward in that a concentrated solution of polymeric material (in this case the adhesive and adhesive primers), and other additives are mixed in situ with high-pressure (in the range of 1000 psi to 2000 psi) carbon dioxide and then sprayed. In practice, the process is complicated in that one is mixing an incompressible, highly viscous material (polymeric material and solvents) with a highly compressible fluid of very low viscosity (supercritical carbon dioxide). The solvents are mixtures of fast and slow evaporating VOCs which are chosen specifically for their ability to dissolve the polymeric material, reduce viscosity, and aid in atomization and droplet coalescence on the substrate. In the supercritical spray process, supercritical carbon dioxide replaces that fraction of the organic solvent that is needed to give the viscosity reduction necessary for spray atomization. This is also the solvent that is the primary contributor to the high VOC emissions.

For a polymeric material to be adapted to the UNICARB process, the phase behavior of that particular polymeric material (the adhesive in this case) with carbon dioxide has to be known. Mixtures of high-pressure carbon dioxide with the adhesive concentrate must exist as a single phase at elevated pressures for the UNICARB process to work. To date, little is known of the phase behavior of polymer-solvent-carbon dioxide mixtures, and determining the underlying thermodynamic and rheological behavior is an arduous trial and error process. Additionally, precipitation of solids in solution has been encountered and needs to be avoided when using this process.

This project will adapt the UNICARB spray application process to adhesives in two ways: (1) a continuous process for use in a manufacturing setting, and (2) a portable hand held batch process for use in small jobs or repair scenarios. Each of these processes requires its own unique set of phase diagrams given that the portable device operates in dynamic conditions (the materials and pressures of the system are changing with time), whereas the continuous spray operation operates in a steady state mode (the system pressure and material compositions remain constant with time). Therefore, for each adhesive adapted to the UNICARB process, two different types of phase diagrams will need to be generated.

The goals of this 4-year project are to adapt six non-structural adhesives to both a continuous and portable UNICARB process. The following approach will be taken:

- The polymeric material and solvent constituents of the six adhesives will be evaluated for their compatibility to the process.

- The identity and proportion of the various high and low volatile solvent constituents comprising the present adhesive mixture will be determined.

- Once the phase behavior is determined the configuration of the batch and continuous process will be established and tested.

- Based on the above tests, formulation of the supercritical carbon dioxide-solvent-polymer mixture will be further investigated for optimization of performance properties and minimization of environmental impacts.

- After determination of the optimal adhesive formulations, both processes will be field tested on various applications at venues to be determined by the respective military collaborators for this project.

- For each adhesive that is reformulated and adapted to the UNICARB process, a concurrent effort will be made to develop the underlying thermodynamic and rheological behavior.

Risks include: incompatibility of the solvent/polymer system with the phase behavior requirements of the UNICARB process; failure to meet military performance specifications; and inability to adapt the portable hand-held spray device to a two-phase UNICARB process.

**BENEFIT:** The principle cost benefits of this project will be from reformulation of existing adhesives now used by the military, and reduction in environmental impacts associated with the VOCs. By re-engineering the UNICARB process to one that can be applied with a hand-held device, the military will be able to increase the number of applications and venues where environmental compliance can be achieved. The advantages of adopting this process include: reduction in VOC emissions; reduction in solvent costs; use of existing and proven adhesives and primers; more evenly distributed coatings; reduction in labor costs; reduction of worker health and safety costs; and, reduction of costs associated with hazardous material management respective to permits and emission control equipment.

**ACCOMPLISHMENTS:** Two adhesive systems, acrylic and neoprene, to date have been selected for study. Examination of the neoprene system was commenced. To increase test speed and accuracy, work has been conducted on automating the data acquisition process by including an automated piston controller and modifying the automated data collection computer.

**TRANSITION:** Two key customers, Tank Automotive & Armaments Command and Aviation & Missile Command, have expressed interest in participating in the program. Additionally, the Principal Investigator plans to work with adhesive manufacturers and equipment companies.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Critical Factors for the Transition from Chromate to Chromate Free Corrosion Protection; PP-1119

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Rudolph Buchheit; Ohio State University – Columbus, OH

**FY 2000 FUNDS:** $480K

**DESCRIPTION:** The overall objective of this research program is to acquire a fundamental understanding of the chemical and physical processes and mechanisms of corrosion protection by chromate-based coatings applied to metal surfaces with a specific focus on corrosion protection of aluminum alloys. Specific objectives of this program are to: (1) define a set of phenomenological and fundamental rules that describe the role of microstructural heterogeneity in chromate conversion coating formation and breakdown; (2) define the relationship between chromate conversion coating structure and chemistry, and coating properties for coatings applied under non-ideal conditions such as those that exist during coating applications in manufacturing and military maintenance depot environments; (3) determine the extent to which application method, coating age, and alloy substrate chemistry affect the self-healing nature of chromate coatings; and (4) develop rapid, quantitative, and predictive tests to assess properties and performance of chromate conversion coatings.

This program comprises a four year fundamental research effort conducted jointly by Ohio State University, the Air Force Research Laboratory, and the Army Research Laboratories. Informal technical collaborations are planned with the Air Force Corrosion Program Office, the Aluminum Company of America - Alcoa Technical Center, and the Naval Air Defense Center.

**BENEFIT:** Chromate corrosion protection technologies are expensive to operate and generate much hazardous waste. These technologies will be replaced only when environmentally friendly corrosion protection technologies achieve acceptable levels of performance. Until there is a framework for understanding and defining the attributes of the chromate coatings that result in their superior performance, consistent forward progress in development of chromate-free coating performance should not be expected. The expected benefit of this research is gains in the fundamental understanding of the chemical and physical processes and mechanisms of corrosion protection of chromate-based coatings that will support the development of effective chromate-free alternatives.

**ACCOMPLISHMENTS:** Microstructural and chemical characterization of aluminum armor alloys 2519, 5083, and 7039 has been completed. A specially designed small length scale electrochemical cell has been constructed to support intermetallic compound (IMC) studies. Two new studies focusing on the effect of variable copper concentration on chromate conversion coating (CCC) formation on 7XXX alloys, and the effect of overaging on CCC formation have been initiated.

It was demonstrated that Raman spectroscopy can be used to monitor epoxy primer curing, to examine the state of chromate pigments in primer coats and to examine parts from 30 year-old aircraft parts. Detailed "fingerprints" have been identified that will permit assessment of structural and chemical changes due to weathering. The effects of CCC aging at ambient and elevated temperature have been studied. Studies examining the kinetics of loss in corrosion resistance were carried out in conjunction with personnel at Brookhaven National Labs.

A study comparing the relative contributions of adhesion and corrosion protection to the overall performance of chromate-containing coating systems has been initiated. An EIS-based test method is under development as a rapid predictive accelerated test methodology for chromate coatings. Initial results suggest that solution volume to surface area ratio can be manipulated to sense self-healing effects in CCCs. Follow-on tests have verified initial findings.

**TRANSITION:** All Services and DoD partners will be apprised of initial results from this fundamental research and will be used to aid in modifying procedures and specifications for corrosion protection by coatings. Two presentations were given at the electrochemical society meeting and two manuscript have been submitted for review. The first presentation and paper focused on the effects of aging and heating on CCC structure, chemistry and properties. The second presentation and paper focused on the role of microstructural heterogeneity on Cu redistribution during aqueous processing.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Mechanisms of Military Coatings Degradation; PP-1133

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Steven McKnight; U.S. Army Research Laboratory – Aberdeen Proving Ground, MD

**FY 2000 FUNDS:** $700K

**DESCRIPTION:** Military coating systems are usually repainted for the following reasons: loss of appearance (aesthetics, camouflage, cleanliness); chipping, peeling, debonding of the coating; and corrosion of the substrate. The primary technical objective of this project is to identify, model, and predict degradation mechanisms that lead to military coating system failures and force depaint/paint operations to occur. An overall deliverable of the proposed effort would be pollution prevention via intelligent reduction of the paint/repaint frequency. The project will develop models of coating degradation and provide a scientific basis to develop new durable coating formulations that will help to achieve this goal. The research findings will be transitioned through appropriate vehicles to the Army, Navy, Air Force, and Marine Corps. The outcome of this program will have a positive impact on both pollution prevention and cost avoidance to the Department of Defense.

This program will pursue a multi-disciplinary highly leveraged approach to study the degradation mechanisms leading to paint/repaint operations. The complexity of the problem demands complementary studies to fully understand the degradation mechanisms. In this work, we have selected to study the mechanisms of military coatings degradation used on aircraft (NAVY), combat ground vehicles (ARMY, MARINES), and support equipment (NAVY, ARMY, and MARINES). Efforts will focus on primer/topcoat systems that are being fielded to comply with environmental legislation and regulations. Both accelerated tests as well as static and dynamic field conditioning to assess coatings degradation in military systems and environments will be investigated. Most prior coatings degradation work has focused on commercial systems and has attempted to relate accelerated lab tests to actual service conditions. The response of any coating system to the environment is complicated and depends on resin type, pigment-resin, primer-topcoat, and primer-substrate interactions. Each element must be addressed to fully understand the degradation mechanisms of the coating system as a whole. This program will quantify and model the degradation modes that lead to these failures. The end result of this project will be an understanding of the mechanisms that explain the degradation of organic coating systems when exposed to military type environments. These mechanisms will be modeled and included in a statistical method for accurately predicting the performance of coating systems. Furthermore, an extensive database will be published on the World Wide Web as well as formal reports that document results from accelerated aging, static weathering, and dynamic weathering of the new water-reducible coatings systems that are targeted for insertion in the near future.

**BENEFIT:** Since this basic research program focuses on fundamental knowledge and predictive service life models, the return on investment will be subtle, yet could be quite substantial. In general, the pay-off to the military from reduced paint/depaint operations would be realized through reduced environmental pollution, cost savings, and improved force readiness. A thorough and quantified understanding of the mechanisms of coatings degradation will promote further confidence in environmentally friendly coatings and thereby increase acceptance of these new systems. Improved confidence will result in faster implementation of the low VOC coatings on military platforms.

**ACCOMPLISHMENTS:** Research has yielded useful data concerning the effect of UV exposure on moisture transport. The results have attracted attention from the technical community and the researchers were invited to present the work at the annual American Institute of Chemical Engineers (AIChE) meeting session on degradation kinetics in thermosetting materials. The work has shown that initial corrosion resistance may be compromised after UV exposure. The data were used to validate the two phase Fickian diffusion model that has been developed to predict the concentration of moisture in the primer/topcoat

system at any given time. The model continues to show good agreement with experiment and shows that predictive modeling can be used in certain instances. New work has shown the influence of increased topcoat diffusion on the system performance. The model was able to capture these effects, and showed that the primer properties are even more critical after the topcoat has degraded due to exposure to UV. This work has been published in a series of ARL tech reports as well as technical briefings.

Work was also focused on sample fabrication, preparation of samples for examination, and initial measurements of properties. Finalization of characterization methods and their application to coating systems of interest in this program has been initiated. Specifically, a robust method of producing free standing films for dynamic mechanical analysis and thermal analysis has been successfully identified. Spectroscopic examination of the coatings of interest has been initiated. XPS studies of the surfaces have just commenced. Baseline XPS spectra have been obtained.

**TRANSITION:** The results and models will be transitioned by promoting their use, as bases for defining performance criteria, and in the contracts issued during the acquisition (or rebuild) process. Additionally, the models can be incorporated into materials specifications and/or manuals as criteria for qualification or use. Finally, standardization and industry acceptance of such models would be pursued (FED STD, ASTM, SSPC, NACE, etc.).

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Development of Innovative Nondestruction Evaluation (NDE) Technologies for the Inspection of Cracking and Corrosion under Coatings; PP-1134

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Ms. Michele Novack; U.S. Naval Surface Warfare Center – Carderock, MD

**FY 2000 FUNDS:** $625K

**DESCRIPTION:** The objective of this program is to develop and evaluate three technologies for their viability as nondestruction evaluation (NDE) tools for the detection of cracks and corrosion under surface coatings in aircraft and ground vehicle applications. They have been developed in the private sector under either private or SBIR program funding and have shown promise for meeting the technical and sometimes unique logistical needs of DoD aircraft and ground vehicle applications. These technologies include: (1) Ultrasound Imaging, (2) Thermal Imaging, and (3) Near-Field Microwave Imaging. These technologies were proposed for investigation based on their potential to inspect areas rather than points (translating into efficient levels of inspection scan rates), portability to the job site, overall projected economy to implement, and relative technology maturity. Two of the techniques, Ultrasound and Microwave Imaging, are believed to be effective in detecting cracks under coatings and will be investigated for that purpose, as well. In parallel to NDE techniques development, models will be developed to correlate with the output signature of these various techniques. Electrochemical Impedance Spectroscopy (EIS) will be used to validate the measurements. Finally, a "round robin" test will be performed to determine the most effective NDE technique for detecting corrosion.

**BENEFIT:** Conventionally, the problems of corrosion (chemical degradation) and fatigue cracking (mechanical degradation) have been addressed through the application of surface coatings and NDE inspections (e.g., eddy current or magnetic particle methods). These practices remain a significant portion of the maintenance budget for each system and play a major factor in overall system readiness especially since the conventional NDE methods require the removal of surface coatings in order to conduct interrogations of the metallic substrate. According to a recent estimate, the ability to detect and repair corrosion areas prior to severe degradation will reduce operational maintenance cost by 25 percent and will improve operational readiness.

**ACCOMPLISHMENTS:** Naval Air Warfare Center (NAWC) initiated production of lab-scale crack specimens. NAWC also received ultrasonic imaging components for their laboratory evaluation work. The components were then assembled into a pre-prototype instrument for a thru-transmission immersion inspection trial. NAWC modeling work on the thermographic technology is continuing. A lab study was conducted to evaluate the performance of surface treatments that could optimize the performance of the reflector shroud.

**TRANSITION:** All Navy Ship Systems experimentation stations will be apprised of the results from this program for actual in-service field trials. Additionally, some technologies may prove to be mature enough for transition to commercial development will be pursued. The researchers have produced two papers titled "Thermography for Characterization of Corrosion Damage," and "Real Time Ultrasonic Imaging Using a CCD Camera". These will be presented at the March 2000 annual meeting of the National Association of Corrosion Engineers (NACE); and at the 54th Meeting of the Machinery Failure Prevention Technology Society in March 2000 respectively.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Primerless RTV Silicone Sealants/Adhesives; PP-1135

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Dean Martinelli; U.S. Army, TACOM-ARDEC – Picatinny Arsenal, NJ

**FY 2000 FUNDS:** $745K

**DESCRIPTION:** Room temperature vulcanizing (RTV) silicones, developed in the late 1940's, have played an important role in the design and superior performance of weapon systems (airplanes, missiles, electronics, ammunition, vehicles and nuclear weapons) developed by the DoD and DOE. A unique combination of properties has made them the material- of- choice for designers wanting to improve and increase weapon performance. RTV silicones are used as adhesives, sealants, coatings, heat insulators and encapsulating materials. For RTV silicones to achieve a high level of consistent adhesion to various substrates, a saline primer is applied prior to silicone application. These primers contain 90-98% volatile organic compound (VOC) solvents, which evaporate into the air. The objective of this project is to develop, evaluate, and transition a primerless self- bonding low temperature curable addition cured silicone, which eliminates the use of high VOC primers without compromising durability, compatibility, thermal resistance and long term stability.

The project will be conducted in four phases. In phase I, current addition cured silicones available off the shelf will be modified with a bifunctional adhesion promoter compound. In phase II, a less inhibiting adhesion promoter, based on structures defined by molecular modeling will be utilized in an attempt to develop room temperature curing systems. Laboratory adhesion evaluations will be used to establish "go/no go" criteria for technology development in phase II. To expand adhesion capability to a variety of substrate materials, including plastics, novel adhesion promoting concepts will be evaluated in phase III using guidance from molecular modeling predictions. Phase IV will demonstrate the use of a new primerless silicone formulation.

**BENEFIT:** By eliminating the use of the traditional primers, development of this technology will provide several benefits: a reduction of over 500,000 lb/yr of VOCs; avoidance of costs from waivers, deviations and fines associated with the use of non-compliant materials; savings derived from reduced hazardous waste disposal costs; improvement of throughput; reduction in inventory management costs; and cost savings from reduced purchasing, material handling and specification consolidation.

**ACCOMPLISHMENTS:** Substrate materials for third-generation formulations were finalized. Quantum calculations for the hydrosilylation reaction were completed. Baseline studies that investigated methods for environmental testing of adhesively bonded aluminum samples using a Mode II testing method were also completed. Baseline studies for the second-generation formulations were conducted and several second-generation adhesion promoters were selected, synthesized, and screened.

**TRANSITION:** The transition of this technology will occur through revision of military specifications (MIL-A-46106, etc.) and by modification of current data packages with engineering change proposals.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Nondestructive Testing of Corrosion under Coatings; PP-1137

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Ms. Joanne McLaughlin; Northrup Grumman Corporation (NGC) – Pico Rivera, CA

**FY 2000 FUNDS:** $549K

**DESCRIPTION:** Surface corrosion on aluminum aircraft skins and around joints and fasteners is often the precursor to buried corrosion. Aircraft paints are routinely removed to reveal the presence of corrosion on the surface of metal structures and the aircraft is subsequently repainted. Aircraft painting and repainting operations result in significant emissions of volatile organics, organic and inorganic hazardous air pollutants, and hazardous waste. The objective of this project is to develop nondestructive inspection techniques to detect the presence of corrosion under an organic film in order to reduce the amount of painting and depainting that is performed. This project will develop: (1) a spectral NDE technique employing an optical reflectance probe in the near/mid IR region combined with Directional Hemispherical Reflectance (DHR) and FTIR integrated detector; (2) Wide-area spectral imaging (WASI) using spectral filters and high-resolution focal plane cameras to allow rapid initial assessment of sub-paint corrosion; and (3) a Scanning Kelvin Probe (SKP) electrochemical method employing a calibrated capacitance probe to indirectly measure corrosion potential across a surface. Challenges to be overcome include probe positioning and electrical noise.

The project consists of five tasks over four years: (1) baseline measurements of unexposed coatings and typical corrosion products to build up a database of standards; (2) evaluation of aged aircraft components; (3) optimization of measuring systems at varying levels of corrosion and their modification for field use; (4) prototype verification (in conjunction with NAWCAD); and (5) preparation of a transition plan for cost-effective applications.

**BENEFIT:** Minimizing the number of times the aircraft exterior coatings are stripped and reapplied provides substantial pollution prevention and cost saving opportunities. The inspection and measurement techniques can be used to target and map specific areas that require maintenance due to corrosion, thus eliminating the need to completely strip and reapply the exterior coatings. The inspection and measurement techniques provide a means to verify the condition of coating thus allowing for a switch to a condition-based rather than schedule-based maintenance. The inspection and measurement techniques provide a means to verify the condition of the primer and surface preparation once the topcoat has been removed thus eliminating a portion of the rework that now routinely occurs.

**ACCOMPLISHMENTS:** The preparation of corrosion test specimens per the initial test work order has been completed and the specimens were shipped to Brookhaven National Laboratory and NGC's research facility in Bethpage, NY for evaluation using the electrochemical and infrared imaging techniques. In addition to the corrosion specimens, free-standing paint films were prepared for the following coatings: MIL-P-85582, TT-P-2760, MIL-C-85285, and MIL-S-81733 over the range of 1 to 10mils. Using the IR imaging technique, the directional hemispherical reflectance of the free-standing films was determined. Overall it was shown that very low levels of substrate corrosion could be imaged through these standalone coatings. The next phase of the test program will require application of the various coating systems to the corroded substrate to ascertain if the corrosion is detectable at these low levels.

In summary, the following preliminary findings were obtained: the electrochemical and IR imaging technologies were capable of detecting extremely low levels of corrosion under simulated paint films; for the spectral imaging technique, the polysulfide film was the least transparent; and for the electrochemical measurement system, direct measurement of contact potential appears to be the most promising for field application although the scanning kelvin probe will be required to provide a measurement baseline.

**TRANSITION:** Weapon systems will be identified that can use the spectral imaging and electrochemical measurement technologies to assess the condition of underlying substrates relative to corrosion without coatings removal.

# PROJECT SUMMARY

**PROJECT TITLE & ID:** Cleaning Verification Techniques Based on Infrared Optical Methods; PP-1138

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. David Otteson; U.S. Department of Energy, Sandia National Laboratory – Albuquerque, NM

**FY 2000 FUNDS:** $565K

**DESCRIPTION:** The objective of this project is to develop a real-time method to provide both qualitative and quantitative assessments of surface cleanliness for a wide variety of military cleaning applications. The introduction of new environmentally acceptable solvents for traditional chlorinated hydrocarbon materials has produced major uncertainties in standard cleaning procedures. As a result, many applications overutilize solvents to ensure component cleanliness and the success of any subsequent processing operations (such as coating or bonding). This, in turn, leads to the additional usage, handling and disposal of hazardous materials, while also wasting personnel operating time. This project will develop two prototype infrared-optical instruments with complementary capabilities for use at DoD sites that will reduce the use, emission and handling of hazardous materials in cleaning operations, and will also be applicable to DOE and commercial sector needs.

Currently, the detection of surface contamination on reflective surfaces is most convenient and rapidly done by the fourier transform infrared reflectance (FTIR) method which provides both quantitative and qualitative information on surface coatings. However, it is greatly limited in its ultimate sensitivity to surface contaminants by the nature of its optical design. DOE's Sandia National Laboratory, in partnership with Naval Facilities Engineering Service Center (NFESC), propose to develop two prototype instruments with complementary capabilities for cleaning verification. In each case, surface contamination will be detected via alteration of the grazing-incidence infrared reflectance of the surface. Specifically, the project will: (1) develop a prototype on-line widely tunable infrared laser based instrument with high speed surface-imaging capability but with limitations on the number of detectable organic contaminants; and (2) optimize an FTIR based instrument with high sensitivity for organic species on a variety of surfaces, but with limitations on speed and surface coverage for real-time analysis of surface contaminants at very low level of concentrations. The proposed instruments will differ in the nature of the information they provide. The first will produce images that directly indicate the spatial extent and location of contamination. The second will provide a spectrally-resolved measurement of the surface reflectance at a single point.

**BENEFIT:** This project will develop two infrared optical methods that address the need for new surface cleanliness analysis technologies and will benefit DoD operations in several ways. The methods will be able to: (1) operate in real-time and will be useful in process monitoring and control; (2) provide qualitative and quantitative output for comparative assessment of cleanliness levels (both quantitative amounts and species present); (3) handle a wide variety of military specific applications, such as repair and remanufacturing processes at repair depots; and (4) measure cleanliness levels such that they can be related to required materials property requirements for various surface preparation processes (e.g. repair or application of protective coatings)

**ACCOMPLISHMENTS:** Work was completed on the infrared-laser optical interface for laboratory imaging of surface hydrocarbon contaminants. A noise level of 1percent for the ratio of tunable laser images at different wavelengths was demonstrated, thus satisfying the FY99 Go/No-Go decision criterion for the infrared-laser portion of the cleaning verification monitor development project. The infrared laser cavity is being operated with stepped periodically-poled lithium niobate (PPLN) crystals that have the capability to detect hydrocarbon contaminants as well as the presence of residual water and the extent of surface roughness. It was found that adjacent periods of the PPLN crystal can be tuned to on- and off-resonance absorbance bands for hydrocarbon contaminants, an approach that will greatly enhance the speed and ease of use of a prototype instrument for the detection of residual hydrocarbon contaminants.

Three levels of surface contamination of the first hydrocarbon component (a soft, opaque grease) were applied to three Al test coupons for each of six surface finishes, creating a suite of 18 panels for evaluation. Several techniques were attempted for an even application of the thin films, and airbrushing was chosen as the best method for this particular contaminant. The grease contaminant was then heated on the surfaces of the coupons for stabilization and subsequent quantification by weighing. FTIR grazing-angle reflectance spectra were obtained for the 18 coupons at two angles of incidence (75 and 80 degrees), with and without a masking aperture, and for longitudinal and transverse surface finish directions. It is expected that these data will substantially influence the design requirements of the prototype FTIR (and laser imaging) instruments.

**TRANSITION:** Transition to both research and development organizations and DoD end users will be integrated over the life of the project through field testing at DoD facilities, communicating the results to DoD and DOE users, and aggressive pursuit of commercialization. A new project to develop a cleaning verification monitor for residual energetic materials in demilitarized components using the tunable infrared laser system at Sandia was initiated. Synergism between the existing SERDP project and this new work should accelerate transitioning of the technology to the DoD and commercial sector. Additionally, a technical presentation was provided at an SPIE symposium on remote sensing and spectral imaging in Denver, CO, during July 1999, and another paper titled "Laser Applications to Chemical and Environmental Analysis" will be presented at the meeting in Santa Fe, NM, during February 2000. (sponsored by the Optical Society of America).

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Non-Structural Adhesives Requiring No VOCs; PP-1139

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Fred Albert; Montana Biotech Corporation – Belgrade, MT

**FY 2000 FUNDS:** $329K

**DESCRIPTION:** Polymeric adhesives are used in a variety of joining applications in the military and civilian sectors. Adhesives currently in use generally contain epoxy-polyamides, polyurethane, polysulfides, or alpha-cyanoacrylates. These adhesives require toxic volatile organic components (VOC) to polymerize, and therefore pose a significant health hazard. The VOCs commonly utilized include toluene, acetone, methanol, ketone, or xylene. Based on Toxic Release Inventory information (1996), it is estimated that 1.6 million pounds of VOCs are released annually through military use of solvent based adhesives. Personnel at manufacturing and repair facilities are at particular risk since the toxic effects of VOCs are evident at concentrations less than parts per million.

The objective of this proposal is to develop innovative, compliant adhesive polymers that have no requirement for volatile organic compounds. The source of these novel polymers will be microorganisms isolated from high temperature waters. Developed compounds will be environmentally safe, thermostable, and water tolerant. The adhesives will meet the minimum requirements of physical property performance and materials compatibility as generally required by MMM-A-121, A-A-1936, MMM-A-139, MMM-A-1058, MMM-A-1617, and MIL-A-5540.

The overall technical approach of this project is to identify natural adhesive compounds produced by microorganisms isolated from high temperature aqueous environments. 500 microorganisms from the Montana Biotech in-house collection will be grown in mini-fermenters and the cells separated from the culture broth. The culture broth containing extracellular polymers will be subdivided into three crude fractions: whole culture broth, exopolysaccharide, and protein components. Each crude fraction will be tested for tensile adhesive properties and compared to adhesives currently in use by the DoD. For example, the Army currently uses Permatex PR1 (Loctite) and Scotch-Grip 1300L (3M) that meets Mil Spec standard MMM-A-121. Polymers in crude fractions with comparable adhesive properties will be purified to homogeneity. The pure adhesive will be analyzed by time of flight secondary ion mass spectrometry (TOF-SIMS) and attenuated total reflectance fourier transform infrared spectrometry (ATR-FTIR). TOF-SIMS will generate information regarding the structure and composition of the adhesive compound and its association with various surfaces. ATR-FTIR data will include the kinetics of adhesion and bond stability on hydrophilic and hydrophobic surfaces. The physical performance of the pure adhesive polymer will be determined using mil spec standards for tensile and shear properties. If the native microorganism proves to be problematic in terms of adhesive production, and the adhesive is a protein product, the gene encoding the adhesive compound will be identified and cloned into a more industrially applicable microorganism.

**BENEFIT:** The Army, Navy, and Air Force apply non-structural adhesives to a variety of systems including gaskets, instrumentation panels, textiles, packaging and labeling. Millions of pounds of VOCs are released annually through use of currently available adhesives. Executive Order 12856, Clean Air Act, Clean Water Act, RCRA, CERCLA, NASHAP demand the reduction of VOC emissions into the atmosphere. DoD use of adhesives identified by this project will directly respond to executive orders for reduction of VOC emissions, and reduce the health risk of military personnel. The potential beneficial uses of these adhesives include molecular sensors, biodegradable plastics and viscoelastic food additives. Medical applications include biocompatible tissue augmentation, wound closure and drug delivery systems. DoD will not only benefit from the reduced costs of implementing non-VOC adhesives, but also benefit from the improved thermostability and water tolerance of these novel adhesive compounds.

**ACCOMPLISHMENTS:** 70 of the planned 80 pre-selected microbial isolates have been tested to date. Each isolate was used to innoculate nutrient rich and nutrient poor media. Isopropyl alcohol extracts of each microbial culture have been screened in house for adhesive strength using aluminum 2024 and EPDM rubber coupons. Approximately 50% of the tested extracts demonstrated at least 5 psi flatwise adhesive strength. These extracts were used to adhere aluminum 2024 milled bolts for Instron testing by Salient Technologies. Approximately 10% of the original number of extracts have demonstrated at least 10 psi flatwise adhesive strength. Several extracts demonstrated at least 20 psi. This is comparable to the metrics, 3M 1300 and Permatex PR-1, that demonstrate 42 and 12 psi with the same surface respectively. It is estimated that the unrefine extracts are at best 5% pure, and further purification may increase adhesive strength.

**TRANSITION:** The non-structural adhesives will be tested as necessary to qualify for Army, Navy, Air Force, and DOE applications as well as for use in the private sector.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Electro-Spark Deposited Coatings for Replacement of Chrome Electroplating; PP-1147

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Joseph Argento; U.S. Army Armament Research, Development, and Engineering Center – Picatinny Arsenal, NJ

**FY 2000 FUNDS:** $587K

**DESCRIPTION:** Chrome electroplating is one of the most widely used surface treatment processes throughout the military services, and represents the most significant contribution to hazardous, carcinogenic waste generation and pollution control costs. The current alternative technologies such as high velocity oxygen fuel (HVOF) process are gradually replacing chrome electroplating for some applications. However, there currently exists a need for alternate technologies where alternate technologies such as HVOF coatings cannot be applied due to geometry constraints or because of service conditions exceeding the damage resistance of the HVOF coating.

In recent years, electro-spark deposition (ESD), a novel coating technology has been developed that produces some of the most robust, damage-resistant coatings known. ESD is a pulsed-arc, micro-welding process that uses short-duration, high-current electrical pulses to deposit, with very low heat-input, a consumable electrode material on a metallic substrate. The short duration of the electrical pulse produces very rapid solidification of the deposited material resulting in a nano-structured coating demonstrating unique tribological and corrosion performance. The process releases no hazardous wastes, fumes or effluents, is cost-effective, requires no special chambers, spray booths or operator protection, and eliminates the hydrogen embrittlement problems that can occur with some substrates. Unlike some of the alternate technologies which may produce mechanical or chemical bond, the ESD technology creates a true metallurgical bond while maintaining the substrate at ambient temperatures.

The objective of this project is to develop process control sensors, process parameters, equipment, and techniques using ESD to coat inside diameters and other difficult geometries with robust wear and corrosion-resistant coatings that will replace current chromium electroplating applications. The technical approach consists of developing the process parameters for selected material coatings required for specific military applications, and the process control sensors and algorithms necessary to achieve those parameters in non-line-of-sight applications. Power supply modifications and automated control devices will be developed and used to apply coatings to representative components for each military service. The components will be tested as part of the process optimization efforts, using specific test conditions defined by the military services.

**BENEFIT:** This research will lead to a cost-effective, environmentally-benign process and low-capital-expense equipment capable of providing an improved level of performance relative to current electroplated coatings while reducing or eliminating the need for hard-chromium electroplating. This will complement current replacement technologies, such as HVOF, by allowing coating of non-line-of-sight geometries that HVOF and other thermal-spay processes cannot coat. Cost benefits include: low capital expense (~$30K) compared to new Cr-plating lines (>$1million) or HVOF (>$400K); elimination of waste disposal costs, $0 for ESD compared to >$10 million per year reported for Cr-plating for the Army alone; reduced or eliminated surface preparation costs relative to either Cr-plating or HVOF processes; and savings from portability of process to allow use in field or shipboard to coat or repair components in-place, with minimum set-up.

**ACCOMPLISHMENTS:** This is a FY 2000 new start.

**TRANSITION:** This project will generate a working prototype of ESD system for non line-of-sight (NLOS) surface coatings, and protocols for process testing. Results of the process tests for the military Services will be reported to team members and to the technical community at the DoD Hard Chrome Alternatives Team (HCAT) and SERDP meetings.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Computational Design of Corrosion Resistant Steels for Structural Applications in Aircraft; PP-1149 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Charles Kuehmann, QuesTek Innovations LLC – Evanston, IL

**FY 2000 FUNDS:** $100K

**DESCRIPTION:** The program's objectives are to design, prototype, and characterize a new corrosion resistant steel that can significantly reduce DoD's use of cadmium during rework, maintenance, and the manufacturing of structural steel components for aerospace applications. The new steel will be developed by applying advanced computational tools, models, and design methodology and will demonstrate the potential of a new method suitable to develop alternative processing paths and materials to replace processes and materials posing increasing environmental concerns.

There are four primary technical Tasks within the program. The specific activities within each Task result from the application of *Materials by Design* approach, which integrates processing, structure, property, and performance relations within a multilevel systems structure. The first task, Analysis, will generate a systems flow-block diagram and calibrate models for the design process. The second task, the Design/Synthesis Task, will determine an alloy composition and the processing variables. During the third task a 300 lb. heat of the prototype material will be acquired and characterized; and the during the final task a technical report will be prepared detailing the program activities and analyzing the feasibility of the alloy design and its potential for further development and commercialization. A prototype of an entirely new corrosion resistant steel will be delivered that will posses similar mechanical properties to those of 300M and be compatible with current and emerging aerospace coating processes such as high-velocity oxygen fuel (HVOF) technology.

**BENEFIT:** The benefits of mechanistic computational design technology is that it is now possible to rapidly develop entirely new materials and processes at costs that are orders of magnitude below the historical application of "trial and error" discovery methodology.

**ACCOMPLISHMENTS:** This is a FY 2000 new start.

**TRANSITION:** QuesTek is working to develop joint venture agreements with alloy producers and landing gear manufacturers to be executed once the proof of concept has been established. The specifications for the proposed alloy and the protocol for material testing and evaluation have been designed to meet the end-user standards of Boeing and BFGoodrich in the U.S., and of Messier-Dowty in Canada.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Electrodeposited Mn-Sn-X Alloys for Corrosion Protection Coatings; PP-1150 *(SEED project)*

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Giovanni Zangari, University of Alabama – Tuscaloosa, AL

**FY 2000 FUNDS:** $94K

**DESCRIPTION:** Cadmium (Cd) has been adopted in a number of military corrosion protection coating applications due to its capability to sacrificially protect steel from corrosion, low galvanic corrosion in presence of Al, and its good lubricity and high conductivity. However, its ascertained toxicity and risks posed to the environment have created the need for alternative coatings. The objective of this research effort is to develop a novel class of environmentally benign electrodeposited Mn and/or Sn based alloy coatings suitable to substitute Cd in most of its current applications as a corrosion protection coating. For those instances where such substitutes would not be suitable, a class of electrodeposited alloy coatings evolved from current substitutes of Cd (Zn alloys with minimum content of toxic metals) will be developed, fabricated by processes with minimum environmental impact. The alloys will be electrodeposited from environmentally friendly electrolytes on test coupons and successively on complex parts. The inclusion of self-lubricating or hard particles in the alloy coating to tune the tribological properties and the electronegativity of the alloy coatings will also be attempted. Thus, this research project attempts to develop an effective, versatile alternative to Cd, thus eliminating the toxic fumes, hazardous waste streams, and the increasing cost, currently associated with the production of Cd plates.

**BENEFIT:** Successful development and implementation of this technology is expected to eliminate the toxic fumes, hazardous waste streams and increasing cost associated with the production of cadmium plating.

**ACCOMPLISHMENTS:** This is a FY 2000 new start.

**TRANSITION:** Transition to this new technology will be facilitated by the use of electrodeposition processes, as the necessary innovation in processing lines would be minimized.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Clean Dry-Coating Technology for ID Chrome Replacement; PP-1151

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Mr. Bruce Sartwell; U.S. Naval Research Laboratory – Washington, DC

**FY 2000 FUNDS:** $542K

**DESCRIPTION:** Chrome plating is heavily used throughout the DoD on almost any system subject to wear - aircraft, ships, tanks, guns, hydraulics, etc. It is used by both original equipment manufacturers (OEM) and overhaul and repair (O&R) depots. In order to avoid all the high volume waste streams inherent in wet plating technologies, the research team proposed dry-coating methods - plasma sprayed WC-Co (Tungsten Carbide-Cobolt) for internal diameter (ID) as small as 1.5". Recent work funded by Defense Advanced Research Project Agency (DARPA), Office of Naval Research (ONR), and the commercial sector has shown that plasma spray with small (1-10um) or nanoscale powders (20 um agglomerates or 20nm particles) produces very smooth coatings with the porosity and adhesion of high-velocity oxygen fuel (HVOF). The hypothesis is that small or nano particle spray with existing ID plasma guns will satisfy most of the needs for landing year (>3" IDs), which is the largest aerospace use of ID chrome. Development of suitable spray method for miniature ID guns will extend the plasma spray process to 1.5" ID to reach most of the actuator components, and modification of these guns may permit us to reach 1" ID for the smallest pins, hydraulic actuators, etc. For some applications, such as sidewalls of grooves in IDs, or very thin-walled, heat-sensitive components, the ESD process is likely to be more cost-effective. ESD is a consumable electrode micro-welding technology with heat input that is extremely small and limited to the surface layer, and it is ideal for small areas and difficult geometries.

The objective of this project is to develop an ID coating technology that is clean, can be used for rebuilds, is environmentally acceptable, and can fit with both the OEM and the depot maintenance production environments. This will be accomplished in four tasks: 1. Conducting research on the deposition of smooth, high quality plasma spray WC-Co coatings on IDs >2.5", using existing guns with small particles and with agglomerated nanoparticles. 2. Developing and testing new miniature ID plasma spray gun for use with small particles and nano-agglomerates which could drive the minimum coatable ID down to 1". and 3. Ensuring that the technologies not only provide good performance at an acceptable cost, but also fit the diverse needs of both OEM and depot maintenance operations.

**BENEFIT:** The immediate environmental benefit of the thermal spray approach is the complete elimination of hexavalent chrome mist and the chrome-contaminated toxic wastes associated with both chrome plating, stripping, and masking operations. The work will lead directly to ID coating methods that are clean and produce a higher quality, longer lasting product. This coating method has the potential for significant cost reduction in both production and sustainment. In general WC-Co coatings last at least 2 - 3 times longer than hard chrome. This leads to lower frequency-of-repair, better mission-readiness, and the ability to keep a lower spare parts inventory. The much reduced production time over chrome plating gives faster turn-around in overhaul operations, also enhancing mission-readiness and reducing inventory requirements.

**ACCOMPLISHMENTS:** This is a FY 2000 new start.

**TRANSITION:** The project is designed to feed directly into an equipment and process development and demonstration/validation program that will be able to follow rapidly upon the completion of the SERDP program. The final deliverable will be a technical report detailing the plasma spray methods that are ready for demonstration and validation.

## PROJECT SUMMARY

**PROJECT TITLE & ID:** Electroformed Nanocrystalline Coatings: An Advanced Alternative to Hard Chrome Electroplating; PP-1152

**PRINCIPAL INVESTIGATOR & ORGANIZATION:** Dr. Maureen Psaila-Dombrowski, McDermott Technology, Inc. – Alliance, OH

**FY 2000 FUNDS:** $200K

**DESCRIPTION:** Hard chromium coatings (0.25 to 10 mil thick) are used extensively for imparting wear and erosion resistance to components in both industrial and military applications. This is because of their intrinsic high hardness (600-1000 VHN) and low friction coefficient (<0.2). The most common means of depositing such hard chromium deposits has been through the use of chromic acid baths. Health risks associated with the use of hexavalent chromium baths have been recognized since the early 1930's, wherein skin irritation and inflammation were identified. More recently, such hexavalent Cr baths have been shown to enhance the risk of cancer of the lung and nose.

Electrodeposited nanoscale coatings of metals and alloys provide the method via grain-refinement (3mm to 100nm avg.grain size) and Hall-Petch strengthening, to produce hard coatings which meet or exceed the hardness and wear performance of current (hard) chromium plating technology. Of particular importance is that these properties are attained using more environmentally benign chemistries (e.g., Fe, Zn, and Co-based systems). The objective of this program is to develop and optimize an advanced nanoscale coating technology based upon modification of environmentally-benign conventional electroplating techniques which will yield coatings that meet or exceed the overall performance and life-cycle cost of existing hard chromium electroplating. The proposed nanoscale coating approach, which is based upon electroplating, would allow for the retention of numerous benefits associated with hard chrome coating technology (i.e., non-line-of-sight application, excellent coating adhesion, dimensional consistency and superior surface finish).

The technical approach will consist of a three-phase program. Phase I provides identification and preliminary experimental assessment of suitable nanoscale electrodeposition systems which satisfy the environmental objective and provide the mechanical performance requirements. This phase will focus upon identifying the most promising systems from an environmental performance and cost perspective. Phase II will deal with developing and optimizing the most promising systems identified in Phase I and will incorporate additional performance evaluation including wear, thermal stability, and corrosion testing. Phase III efforts will be focused upon the optimization of nanoscale 'bore-plating' techniques which represent key applications for the DoD.

**BENEFIT:** This program will allow the complete elimination of hexavalent chromium at rework, maintenance and manufacturing facilities within the DoD. DoD currently spends over $10 million dollars per year in hazardous material disposal costs associated with hard chrome electroplating. The proposed nanoscale coating approach would allow for the retention of numerous benefits associated with hard chrome plating technology (i.e., non-line-of-sight application, excellent coating adhesion, dimensional consistency and superior surface finish). In addition, this approach will allow for the use of existing hard chrome plating infrastructure within the defense sector. This will significantly reduce the time and cost to practical implementation. Moreover, the proposed nano-technology is expected to provide significant performance and life cycle cost benefits over current hard chrome plating technology.

**ACCOMPLISHMENTS:** This is a FY 2000 new start.

**TRANSITION:** It is anticipated that the proposed nanoscale coating technology will fully utilize the existing hard chrome plating infrastructure (i.e., contractors, equipment, specifications, etc.) with minimum

capital expenditure, thus significantly reducing the time and cost to practical implementation within the DoD. The specific deliverables from this project include an environmentally compatible electrodeposition process to replace hard-chrome electroplating, suitable electrodes and fluid delivery system for a DoD non-line-of-sight application, annual reports, peer reviewed articles and design guidance on further applications.

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# APPENDIX E
## FY 2001 Statements of Need

The objectives of SERDP are to support environmental research and development projects to meet high priority, DoD mission-related environmental needs. The major annual, or "**Core**," solicitation occurs each year and provides funding in various amounts for multi-year projects. In FY 1999, SERDP initiated the **S**ERDP **E**xploratory **D**evelopment, or **SEED**, program as a means for researchers to test proof-of-principles concepts during an effort of one year or less. This program is designed to provide support for high-risk, high-payoff projects in which funding is limited to a maximum of $100,000 for one year.

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## SERDP CORE STATEMENT OF NEED FOR FY01 - CLEANUP NEW START

## STATISTICAL SAMPLING FOR UNEXPLODED ORDNANCE (UXO) SITE CHARACTERIZATION

**OBJECTIVE:** The objective of this SON is to solicit proposals to develop scientifically sound sampling procedures that can exploit modern geophysical surveying techniques to characterize sites potentially contaminated with unexploded ordnance (UXO). Statistically valid sampling approaches are needed for the cost-effective investigation of UXO-contaminated sites. The footprint required for detailed geophysical surveys can be reduced if sub-sampling procedures can distinguish, with high confidence, boundaries of contamination within larger sites. Research and development activities at the analytical level and supporting assessments of existing field data and range characteristics will be considered. The product of this research will be the development of statistically valid sampling protocols. Work conducted in response to this statement of need is required to culminate in a protocol ready to be validated through subsequent field demonstrations. Results from this work will provide the data necessary to evaluate the scientific validity and to predict the cost savings and potential risks of the proposed sampling procedure, as compared to currently used techniques.

**BACKGROUND:** As a result of past military training and weapons testing activities, UXO is present at sites designated for base realignment and closure (BRAC) and at formerly used defense sites (FUDS). Current estimates indicate that over 11 million acres of land potentially contain UXO. However, in many cases, the actual contamination is concentrated on subsections of the potentially contaminated land, such as targeting areas. To appropriately direct detailed geophysical surveys, it is desirable to develop a sampling technique whereby a fraction of the site is initially investigated to identify clean and contaminated areas.

## SERDP CORE STATEMENT OF NEED FOR FY01 - CLEANUP NEW START

## REMEDIATION STRATEGIES TO ENHANCE IN-SITU MIXING OF CONTAMINANTS AND CHEMICAL/BIOLOGICAL ADDITIVES

**OBJECTIVE:** The purpose of this statement of need (SON) is to solicit proposals to develop engineering strategies to enhance the in-situ remediation of subsurface groundwater contamination by facilitating in-situ mixing of contaminants and chemical and/or biological additives. This SON seeks improved delivery systems/methodologies for chemical and/or biological additives in the subsurface that will overcome the limited extent of mixing that is achieved with current methods. The research should focus on developing practical and cost-effective engineering subsurface delivery systems or methodologies. The research should lead to a better understanding of what site specific factors control these mixing processes in the subsurface environment and how to cost effectively identify them as an aid to design site specific remediation approaches. Development of a greater understanding of and improved methods to enhance in-situ mixing of contaminants and chemical and/or biological additives will help facilitate the establishment of more cost-effective and efficient remediation technologies that are protective of human health and the environment. The improved chemical / biological delivery systems that will be developed through this SON will enhance the reliability and performance of in-situ remediation processes.

**BACKGROUND:** There are nearly 17,000 sites on Department of Defense installations potentially requiring environmental cleanup. The challenges facing those responsible for cleanup include selection of appropriate remedial actions that will treat the contaminated soil and groundwater to established cleanup standards.

Engineered in-situ treatment processes are actively being developed for management of contaminants in groundwater. Such engineered systems are especially needed when natural processes for achieving acceptable endpoints for contaminants are not present or are not fast enough to be protective at the site. The general approach with engineered remediation is to bring the contaminated soil and/or groundwater and chemicals together for in-situ chemical or biological transformation of the contaminants. Examples of engineered in-situ systems involving chemical and/or biological additives for enhancement of in-situ transformation processes include, but are not limited to: (1) the addition of electron donors and oxygen for aerobic cometabolism of chlorinated solvents; (2) the addition of electron donors for anaerobic reductive dechlorination of chlorinated solvents; (3) the addition of electron donors for microbial reduction of perchlorate to chloride; (4) the addition of chemical reductants for treatment of chromate contamination; and, (5) the addition of microorganisms for the purposes of bioaugmentation. The absence of turbulent conditions in the subsurface means that little mixing occurs when a chemical and/or a biological agent is injected. The limited mixing during simple injection of a chemical means that only a narrow portion of the contaminated zone can be treated which lessens the usefulness of an engineered in-situ approach. Subsurface mixing in groundwater can be improved by employing a funnel-and-gate system, one or more recirculation wells, or a combination of extraction and injection wells. However, these approaches can be costly. Research is needed to develop good delivery systems for chemical/biological additives in the subsurface and an understanding of how to deploy them to satisfy site-specific conditions.

## SERDP CORE STATEMENT OF NEED FOR FY01 - CLEANUP NEW START

## IN-SITU MANAGEMENT OF CONTAMINATED MARINE SEDIMENTS

**OBJECTIVE:** The objective of this statement of need is to solicit proposals to develop innovative technologies to support the cost-effective in-situ, non-removal management of contaminated marine sediments. Research and development proposals for the characterization, monitoring, in-situ remediation, and/or containment of contaminated marine sediments are sought. The focus of this statement of need is undisturbed, contaminated marine, estuarine, and brackish sediments. Potential research efforts could focus on:

- technologies for rapid, accurate cost effective characterization of sediments;
- technologies for in-situ remediation of sediments through either biotic or abiotic means;
- stabilization/containment technologies which significantly reduce the bioavailability of contaminants and/or;
- monitoring technologies to assess the performance of in-situ treatment and/or containment technologies and the status of contaminated sediments not requiring active remediation.

Proposers should demonstrate how their effort will complement, interact with, or enhance other research, development, or demonstration activities addressing in-situ containment and treatment of contaminated sediments. The proposed research and development should lead to cost-effective, characterization, monitoring, remediation or containment technologies as demonstrated by the projected life cycle cost of the technology, including procurement, installation, operation, maintenance, and monitoring. The effort should result in a fundamental understanding of the chemical, physical, and biological phenomena relating to the efficacy of the proposed technology for remediation/containment of contaminated sediments.

**BACKGROUND:** Contaminated sediments are ubiquitous in U.S. estuaries and coastal waters. The level of contamination varies widely with contaminants sometimes becoming concentrated in hot spots. Contaminants cover a broad range of chemicals including petroleum products, dioxins, polychlorinated biphenyls (PCB), heavy metals, pesticides and nutrients. Due the fact that feeder streams pass by/through many contaminant source areas, sediments almost always contain a mixture of contaminants. As sediments are made up of fine-grained, organic-rich materials, many of which are clays, contaminants such as heavy metals and hydrophobic organics tend to sorb onto these particles within the sediments. Sediments tend to be naturally retained in estuaries where they accumulate providing a continual source of potential contamination to the ecosystem. These contaminants can re-enter the water column and ecosystem through bioturbation, resuspension by hydrologic or anthropogenic events or through contaminant flux between the sediments and the water column.

## SERDP CORE STATEMENT OF NEED FOR FY01 - CLEANUP NEW START

## DEVELOPMENT OF ECOLOGICAL SOIL SCREENING LEVELS

**OBJECTIVE:** The purpose of this statement of need (SON) is to solicit proposals for research and development to support the establishment of risk-based soil screening levels for ecological receptors. The work should address one or both of the following specific objectives:

a) Relationships between contaminant concentrations in soil and soil biota toxicity.

Research is needed to evaluate the relationship of labile (available, soluble, exchangeable) concentrations of chemicals in soil as it relates to toxicity to plants and soil biota. Soil chemistry parameters are important factors in estimating the availability or toxicity of chemical contaminants in soil. Research is needed to identify and characterize the predominant soil parameters that affect liability (availability, solubility, exchangeability) and relate liability to toxicity of individual chemicals or groups of chemicals. Theoretical and laboratory investigations are required to refine and validate the specific soil parameters and their toxicity to soil biota and plants. Where appropriate, models relating soil chemistry parameters to toxicity in soil would be developed. The chemicals of primary interest to the Department of Defense (DoD) for this research include trinitrotoluene (TNT), trimethylenenitramine (RDX), polychlorinated biphenyls (PCB), and polynuclear aromatic hydrocarbons (PAH).

b) Characterization of bioavailability across trophic levels.

Research is needed to develop data on transfer factors for chemical contaminants from the environment into organisms at lower trophic levels, and across throphic levels (e.g. soil-plants, soil- worms, soil-insects, worms-mammals and birds, etc). Research is also needed on how these transfer factors/rates are affected by chemical and physical soil characteristics, e.g. pH, cation exchange capacity, and organic matter content. The chemicals of concern for this research need include the organic constituents identified under objective a) as well as metals.

**BACKGROUND:** There are nearly 17,000 sites on DoD installations potentially requiring environmental cleanup. The challenges facing those involved in cleanup include distinguishing those sites that pose significant environmental risks from those that pose little risk, prioritizing contaminated sites by the degree of risk posed, quantifying the risks at each site, and developing appropriate remedial actions and cleanup goals where appropriate.

One of the first steps in the ecological risk assessment process involves screening of potential chemicals of concern, measured in the media of interest and compared to a predicted exposure level believed to pose minimal or no ecological risk. Those contaminants found at concentrations below the "acceptable" levels are eliminated from further evaluation; contaminants above these levels are evaluated further in a site-specific baseline ecological risk assessment. While several entities have developed screening levels, EPA has not embraced any specific approach for use nationally. In the absence of EPA-accepted, peer-reviewed screening levels, the practice at most sites is to perform literature searches for toxicity data on each chemical found at the site and develop site-specific soil concentrations to be used as screening levels at the site under investigation. This repetitious approach is very costly and time consuming and does not foster the development and use of a consistent set of values that can be routinely used to identify chemicals of potential concern (COPC).

## SERDP CORE STATEMENT OF NEED FOR FY01 - CLEANUP NEW START

## MICROBIAL PROCESSES FOR THE DEGRADATION OF NITROAROMATIC CONTAMINANTS

**OBJECTIVE:** The purpose of this statement of need is to solicit proposals to increase our fundamental understanding of the microbial processes involved in the degradation of nitroaromatic contaminants and search for ways to improve on these natural capabilities via metabolic engineering. Results from this research will improve our ability to predict and enhance the in situ biodegradation of nitroaromatic compounds in soil and groundwater.

The research should focus on the following specific research objectives:

- Discovery and development of new microorganisms with novel pathways and enzymes for the mineralization of nitroaromatic compounds.
- Improved fundamental understanding of the enzymatic steps involved in nitroaromatic degradation processes.
- Improved fundamental understanding of gene regulation on biodegradation of nitroaromatic compounds.
- Determining the effects of substrate mixtures and metabolites on the aerobic and anaerobic degradation pathways.
- Great differences in the natural reactivity of nitroaromatic compounds have been observed in natural environments. Therefore, an increased understanding of subsurface conditions, which promote or inhibit the transformation/sequestration of nitroaromatic contaminants and their metabolites, would improve our ability to assess and enhance natural attenuation of these contaminants.

Research and development activities at the laboratory-scale, bench-scale, and field studies will be considered. Proposed work should focus on but are not limited to contaminants such as the following: TNT (2,4,6,-trinitrotoluene), RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine), HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine), and Tetryl (n-methyl-n,2,4,6-tetranitroaniline).

**BACKGROUND:** There are nearly 17,000 sites on DoD installations potentially requiring environmental cleanup. The challenges facing those involved in cleanup include developing appropriate remedial actions to address site contamination and treat the contaminated soil and groundwater to established cleanup standards.

Energetics contamination represents a considerable portion of contamination at DoD sites. Much of the explosive contamination of the environment has resulted from manufacturing and load-assemble-package (LAP) processes conducted before and during World War II and the Korean Conflict. Approximately 25 Army sites are or have been involved in explosives manufacturing or LAP activities. About 20 sites are on the National Priorities List and many sites are scheduled for closure under the Base Realignment and Closure Act. Cleanup preparatory to property disposition was initiated in the early 1980s at many sites. Explosives-contaminated soil has often been incinerated, while waste disposal lagoons and washout sumps and ditches have received, or are in the process of receiving, some form of remediation.

## SERDP SEED STATEMENT OF NEED FOR FY01 - CLEANUP NEW START

## UNEXPLODED ORDNANCE (UXO) DETECTION AND DISCRIMINATION DATA PROCESSING

**OBJECTIVE:** Advances are needed in the detection and discrimination of unexploded ordnance (UXO). Items ranging from 20-mm shells to 2000-lb bombs must be detected and discriminated from other non-hazardous items in the subsurface. Algorithms are needed that can exploit data from current state of the art sensors and advanced sensors that are now becoming available. SEED proposals are requested which explore new discrimination techniques and their application to data collected under other ongoing programs. The proposed work should explore the proof-of-concept of new data processing techniques or algorithms using existing data sets. Proposals to collect new data sets will not be considered under this solicitation. The proposed work should, if successful, lead to a continued development effort, which ultimately could result in the implementation of algorithms and demonstration of their performance.

**BACKGROUND:** As a result of past military training and weapons testing activities, UXO is present at sites designated for base realignment and closure (BRAC) and a formerly used defense sites (FUDS). Using current technologies, the cost of identifying and disposing of UXO in the United States is estimated to be in the billions of dollars. Current technology has shown the ability to detect sub-surface UXO, but not to reliably discriminate UXO from other items that pose no risk. Thus, typical survey methods currently employed have an excessive level of false alarms (i.e., a positive response to sub-surface anomalies which do not correspond to UXO). The false alarms are often associated with natural or geophysical clutter, man-made non-ordnance related objects (wires, cans, etc.) or ordnance related scrap (ordnance fragments, tail fins, etc.).

Currently, SERDP is supporting a wide array of efforts addressing the UXO problem that have resulted in significant high quality data sets. Existing data sets will be provided to projects selected under this solicitation for the development of new processing approaches. Data sets will be available from test sites seeded with ordnance, items that typically lead to false alarms, and simple geometric items (spheres, plates, etc.) as well as data sets from simulated and real live sites. Data sets will be available from a variety of geophysical sensors including the EM-61, EM-63, and GEM-3 electromagnetic induction sensors, as well as a total field magnetometer. In addition, limited amounts of radar data collected under SERDP will be available. Other existing data sets may also be proposed to support the development of new processing algorithms.

## SERDP SEED STATEMENT OF NEED FOR FY01 - CLEANUP NEW START

## LONG-TERM MONITORING (LTM)

**OBJECTIVE:** The cost of long-term monitoring of contaminated sites is a significant and growing portion of the Department of Defense (DoD) cleanup program budget. Advances are needed in sensor and supporting technologies (i.e. sampling and data collection) to significantly reduce these costs. SEED proposals are requested which explore new approaches for satisfying the long-term monitoring needs of the DoD. The primary area of interest is monitoring ground water contamination. The proposed work should explore the proof-of-concept for new long term monitoring technologies. Technology development efforts to minimize person hours in the field through new sampling to eliminate purging from monitoring wells, automation of sampling activities, and in-situ sensors are of interest. Cost is the driving issue. Projects should plan to include simple cost assessments for operational concepts to justify future development efforts. The proposed work should, if successful, lead to a continued development effort.

**BACKGROUND:** The costs of long-term monitoring are increasing as more and more sites enter the active remediation and post-remediation stage. Active remediation systems such as "pump and treat" of groundwater and passive remediation systems such as natural attenuation as well as RCRA closure sites often require elaborate and expensive monitoring. This long-term monitoring can be for process control, for performance measurement, or for compliance purposes and can last up to 30 years. Labor costs are a significant portion of long term monitoring costs. Long-term monitoring involves a large amount of time to collect, package, ship, and analyze samples. Waste generated by sample collection must be disposed of and chemical laboratory results can often take up to 3 months to receive in usable form. Improvements in monitoring strategies to reduce the number and frequency of wells sampled and sampling techniques to improve current field sample collection have been developed and are beginning to exploited. New technologies to further reduce costs are required.

The DoD is interested in demonstrating technologies that can reduce the time required, waste produced, and total cost (both dollars and personnel resources) of long-term monitoring. Specifically, DoD is interested in technologies for the monitoring, at levels of regulatory concern, volatile organic chemicals (especially chlorinated solvents), petroleum and related compounds, trace metals, propellants and explosives.

## SERDP CORE STATEMENT OF NEED FOR FY01 - COMPLIANCE NEW START

## MEASURING, CHARACTERIZING, AND CONTROL OF TOXIC RELEASE INVENTORY AIR EMISSIONS FROM DOD MUNITIONS

**OBJECTIVE:** The objective of this statement of need (SON) is to solicit proposals to identify, characterize and, where required, develop innovative and cost-effective technologies for control of Toxic Release Inventory (TRI) air emissions from munitions at testing and training ranges on Department of Defense (DoD) installations and aboard Navy and Coast Guard vessels. Proposals responding to this SON should address some or all of the following objectives:

- Identify and characterize the emission of TRI chemicals in air at DoD installations. Sites should include training and testing ranges and shipboard points of fire (including bag burning of excess propellant and open burning/open detonation of excess munitions), trajectories (i.e., propellant emissions), points of impact, and field cleaning of armaments for both gun and missile munitions. All measurements should address temporal and spatial variability and identification of classes of emissions factors as a function of source type. Use of the state-of-the-art field-portable monitoring technologies to obtain near real-time measurements is strongly desired;

- Develop innovative control technologies to reduce or eliminate TRI emissions from sources listed above where the emissions are known to be significant. New and innovative monitoring technologies and methodologies may also be developed to provide real-time air emissions monitoring data for TRI chemical emissions in air.

**BACKGROUND:** The DoD maintains testing and training ranges on most of its installations for a variety of munition testing and training purposes. This includes small arms firing ranges and large area ranges for artillery and tanks. Also the DoD maintains ocean firing ranges for testing and operations of Navy guns and missiles. Bombing ranges are also maintained as impact sites for both missiles and bombs. On these ranges the expenditure of energetic material to fire the munition and the explosion of the munition creates a wide variety of chemicals.

In order to address the TRI chemical emissions on Federal facilities, Executive Order 12856 directed Federal facilities, including military installations, to adhere to the Emergency Planning and Community Right-To-Know Act (EPCRA). EPCRA does not explicitly exempt military ranges from TRI requirements of its section 313 reporting requirements. Pursuant to EO 12856, each Federal agency must develop voluntary goals to reduce total releases and off-site transfers of toxic chemicals at least 50 percent from 1994 levels by December 31, 1999. Toxic chemicals for purposes of EO 12856 are the toxic chemicals described in EPCRA section 313. DoD facilities subject to EPCRA section 313 reporting requirements must develop facility-specific goals designed to achieve DoD's overall reduction goal. To achieve the agency-wide goal, each DoD facility is expected, at a minimum, to come as close to the 50 percent reduction goal as practicable. The baseline year from which DoD will measure this reduction has been established as 1994.

## SERDP CORE STATEMENT OF NEED FOR FY01 - COMPLIANCE NEW START

## MEASURING, MONITORING, AND MANAGING NON-POINT SOURCE RUNOFF AT MILITARY INSTALLATIONS

**OBJECTIVE:** The objective of this statement of need (SON) is to solicit proposals to develop innovative and cost-effective technologies to identify, characterize, and monitor nonpoint source runoff at DoD installations. Efforts proposed toward this SON must address the diversity of nonpoint runoff sources that may be associated with military activities. Control of runoff should be addressed only where it may be needed. Proposals responding to this SON should address some or all of the following objectives:

- Develop technologies to identify and prioritize potential nonpoint runoff sources and potentially impacted surface water bodies at DoD installations;
- Develop field-portable technologies to provide real-time monitoring of the volume and characterization of nonpoint source runoff from DoD installations, including temporal and spatial variability;
- Develop innovative and cost-effective treatment and/or control technologies, including but not limited to erosion control, runoff detention, sediment management, and oily water treatment; to mitigate the impacts of nonpoint source runoff that are unique to military installations; and
- Advance the state-of-knowledge of the development of total maximum daily limits (TMDL), including the development of geographic information system (GIS) technologies to quantify and model the contribution of DoD sources of nonpoint pollution.

**BACKGROUND:** Nonpoint source runoff pollution is the diffuse runoff of pollutants from land surfaces during wet weather events and other discharges and is recognized as a significant contributor to water quality problems, contributing as much as 50% of the nation's water pollution. Pollutants in nonpoint source runoff vary widely and include eroded sediments, heavy metals, pesticides, and oil and grease. Activities at DoD installations, such as training/testing, the maintenance and operation of military vehicles and aircraft, runoff from roads and bridges, stormwater runoff, and sewer overflows are potential sources of nonpoint source pollution and may potentially impact nearby surface waters.

The 1987 amendments to the Clean Water Act (CWA) and the 1990 Coastal Zone Act Reauthorization Amendments (CZARA) established a number of programs to address nonpoint source pollution. Section 319 of CWA amendments established the Nonpoint Source Management Program, which requires an assessment of the extent of nonpoint source water quality problems and the development and implementation of best management practices (BMP) to prevent water runoff from becoming polluted, and where it is polluted, to reduce the amount that reaches streams, rivers, lakes and estuaries. The 1987 CWA amendments also require the identification of pollution impaired surface water and the development of TMDLs that set the maximum amount of pollution a water body can receive without violating water quality standards. CZARA established goals to be achieved in controlling the addition of pollutants to out coastal waters and requires the development of Coastal Nonpoint Source Control Programs.

## SERDP CORE STATEMENT OF NEED FOR FY01 - COMPLIANCE NEW START

## TRAINING/TESTING RANGE DUST EMISSIONS CHARACTERIZATION

**OBJECTIVE:** The objective of this statement of need (SON) is to solicit proposals to identify, characterize, and monitor the airborne emissions resulting from DoD testing/training activities. Proposals are being solicited specifically to advance the state-of-the-knowledge by:

- Characterizing and quantifying the natural background and upwind source contributions of particulate matter (PM), such as wildfires, windblown or road dust, to regional haze in the vicinity of DoD installations.
- Developing innovative instrumentation to identify, characterize, and monitor the airborne emissions resulting from DoD testing/training activities in order to provide the necessary source contribution information.
- Determining emissions factors from training and operational activities at DoD installations, including quantifying of their variability and uncertainty.
- Developing model components that better describe the generation and movement of the various particulate matter listed above.

**BACKGROUND:** In 1997, EPA promulgated revisions to the National Ambient Air Quality Standards (NAAQS) for ozone and particulate matter and proposed regulations to address the impairment of long distance outdoor visibility resulting from regional haze. The proposed Regional Haze Rule evolved from the 1977 amendments to the Clean Air Act, which established a national visibility goal to prevent visibility impairment in Class I Federal areas (i.e., large national parks and wilderness areas). The visibility impairment is caused by particles in the atmosphere, which include primary particles such as soot, smoke, dust, carbon; primary gases that absorb light, such as nitrogen oxide; and secondary particles formed by gaseous and hydrocarbon emissions, including sulfur dioxide, nitrates, and carbon-based particles. These particles and gases absorb and scatter light and obscure the clarity and color of objects and landforms over long distances.

DoD training and testing activities at installations across the U.S. often involve the movement of vehicles and personnel on unpaved surfaces, prescribed burning to clear brush and unwanted vegetation, as well as the use of smokes and obscurants for battlefield simulations. Existing dust control technologies, however, fail to meet the U.S. Services need for short curing times and long reapplication intervals on areas that are subjected to repeated disturbance. In addition, road and range maintenance requires down-time which affects the military's training mission.

A primary focus of this requirement is identification and/or development of realistic emission calculations for particulate matter from tracked vehicles, use of smokes and obscurants, explosive demolition, weapons impact testing, artillery practice, and prescribed burning. The secondary focus of this requirement deals with dust suppression and soil stabilization techniques, which must be identified, researched and/or developed, and transferred to allow military installations to conduct training activities with wheeled/tracked vehicles and fixed/rotary-winged aircraft. A tertiary focus area under this requirement involves identification, modification, or development of technology for real-time measurement of air emissions.

## SERDP SEED STATEMENT OF NEED FOR FY01 - COMPLIANCE NEW START

## ANALYSIS, CHARACTERIZATION, AND TREATMENT OF ENERGETIC RESIDUES ON SCRAP MATERIALS AT MILITARY TRAINING/TESTING INSTALLATIONS

**OBJECTIVE:** The objective of this program is to develop innovative and cost-effective technologies to analyze, characterize, and treat energetics residues on scrap materials found on training/testing ranges at Department of Defense (DoD) installations. Proposed efforts must address the diversity of scrap materials and energetics residues found at all types of DoD testing/training ranges for all military service branches. Proposals should address some or all of the following objectives:

- Develop/apply state-of-the-art, field-portable monitoring technologies to analyze and characterize the energetics residues found on the wide variety of scrap materials that are exclusive of unexploded ordnance (UXO) but which include munitions casings, training targets, and other scrap/fragmented materials found at testing/training ranges on DoD installations.

- Develop new, innovative, and cost effective technologies and processes to effectively treat energetics residues typically found on these scrap materials so as to render the scrap materials non-hazardous and suitable for recycling/recovery. Treatment technologies should consider the potential range of sizes of scrap pieces, range of energetic material residues, need for size reduction of the scrap for recycling, and the control and/or monitoring of any effluent (liquid or gaseous) from the treatment process.

**BACKGROUND:** In order to maintain the necessary level of readiness, DoD must conduct realistic training to simulate actual combat conditions. For the foreseeable future, training operations will continue to involve the use of actual equipment and real munitions. These operations result in a substantial amount of energetics contaminated scrap, which must be removed from the range. This scrap must be rendered safe (non-explosive) and non-hazardous before it can be recycled or disposed of as a non-hazardous waste. Safe and environmentally benign methods to treat scrap and residue from testing/training exercise ranges are required. The clearing of the residues will allow these areas to be reused for additional training where reentry by combat troops is necessary in order to obtain realistic training.

The remediation of the scrap material recovered from the ranges is of great concern in that much of the scrap contains varying amounts of energetic materials. If this scrap material is directly recycled by conventional means, e.g., blast furnace melting, there is the potential that some of the energetic residues could detonate with such force as to cause injury and destruction of the furnaces. The complete removal of energetic materials is mandated to ensure the safe recycling of the scrap. Without the verified removal of the energetic material, the scrap salvaged from the ranges will not be reusable. Therefore, the methods that are needed to render the scrap material safe must be able to both ensure the complete removal of the energetic material and determine the presence/absence of any energetic material in the scrap before and after the treatment. At the locations where the scrap remediation does occur, in addition to the need to evaluate range residue treatment technologies, there is a need to identify the resulting emissions and/or wastes (air, liquid or solid) produced by any method that is used to render the scrap ready for recycling.

## SERDP CORE STATEMENT OF NEED FOR FY01 - CONSERVATION NEW START

## ADVANCED TECHNIQUES TO INVENTORY AND MONITOR THREATENED AND ENDANGERED SPECIES IN INACCESSIBLE AREAS

**OBJECTIVE:** The objective of this statement of need (SON) is to solicit proposals for initial or applied development of advanced techniques to inventory and monitor wildlife populations, including threatened and endangered species (TES), in inaccessible areas. Inaccessible areas include firing ranges and impact areas on military installations. Due to the potential risk to human health and safety specific to unexploded ordnance (UXO), it is obvious that the advanced techniques will require some sort of standoff sensing technique(s), e.g. listening devices, imagery, and/or other methods, combined with the appropriate tools to spatially analyze and display results. Proposals should address some or all of the following objectives:

- Development or identification of standoff sensing and tracking techniques to determine the potential occurrence of high priority wildlife including TES located in restricted access and inaccessible areas on installation lands.

- Identification or development of techniques to assess and spatially determine existence and trends of TES habitat associated with species of high priority concern within restricted access and inaccessible areas.

**BACKGROUND:** Department of Defense (DoD) military installations are required by the Endangered Species Act (ESA) to inventory and monitor TES on their lands. This is to support management of these species to avoid impacts and support species recovery. However, a considerable amount of land area on installations is contained within restricted and other inaccessible areas, which prohibit conventional inventory and monitoring. These areas may be inaccessible due to remoteness or terrain, but a primary reason that areas are restricted is because they are impact areas of military ranges. Risk to human health and safety from possible detonation of UXO during surveys in impact areas on military ranges is a primary concern, yet effective management of TES requires that these areas be inventoried and monitored. The areas surrounding these restricted areas are maintained for safety reasons. These safety buffer zones are required to protect the general population from the dangerous conditions that occur during testing and training.

TES compliance decisions are made in consultation with the U.S. Fish and Wildlife Service (USFWS) and are based largely on estimated population viability, potential occurrence of an impact/activity within the critical habitat, and recovery requirements. As a result, installations need to establish individual TES species population goals and habitat requirements. To accomplish this requires more efficient methods to identify populations throughout the installation and to understand TES habitats and population distribution.

The USFWS also places emphasis on management/restoration of critical habitat as a means of maintaining and re-establishing viable populations of TES. Technological solutions are needed to establish viable population numbers, monitoring criteria, and habitat requirements for specific species. Information collected will need to be integrated with landscape/ecosystem models developed for overall ecosystem management and modeling to examine long-term viable population trends, causes of changes, and effectiveness of recovery plans for enhancement of the species at the installation level.

## SERDP CORE STATEMENT OF NEED FOR FY01 - CONSERVATION NEW START

## RIPARIAN ECOSYSTEM MANAGEMENT AND RESTORATION

**OBJECTIVE:** The objective of this statement of need (SON) is to solicit proposals for (1) evaluating the environmental impacts of military land use activities on riparian ecosystems and (2) developing restoration/enhancement methods and conservation management techniques to minimize these impacts and sustain the beneficial services provided by riparian ecosystems on Department of Defense (DoD) installations. The scope of the proposed work should be mindful of DoD's need to conduct rigorous military training and testing while also being good stewards of natural resources. Among DoD's multiple activities impacting riparian ecosystems are combat training exercises, munitions testing, and the deployment of weapons systems. Examples of DoD's major stewardship responsibilities include maintaining sufficient natural habitat and landscape connectivity to support diverse biological communities and protecting endangered and threatened species. Proposals responding to this SON should address some or all of the following objectives:

- Design and conduct field studies that result in increased understanding of the impacts of various military training and other activities on riparian ecosystem components and functions.
- Identify important physical, chemical, and biological requirements that need to be addressed in restoration techniques and management strategies to sustain or enhance riparian ecosystem functions.
- Improve existing, or develop new restoration/enhancement techniques and ecosystem management strategies for sustaining riparian ecosystems that are impacted by various military training and other activities on Department of Defense installations.

**BACKGROUND:** Although riparian ecosystems typically comprise a relatively small proportion of the total landscape, they are among the most diverse, dynamic, and complex biological systems on earth, and contribute significantly to regional biodiversity. The greater availability of water to vegetation, frequently in combination with deeper soils, increases plant biomass and promotes a rich and structurally diverse plant community. This provides habitat for a diversity of birds and animals.

As transitional zones between terrestrial uplands and aquatic systems, riparian ecosystems perform a number of valuable ecological functions. For example, riparian vegetative cover provides soil erosion and sedimentation control and filters toxics and nutrients from terrestrial runoff to enhance water and habitat quality. Because riparian ecosystems offer all three critical resources for wildlife, including food, cover, and water, they provide wildlife benefits far out of proportion to their extent in the landscape. Riparian ecosystems are also of significant socioeconomic, recreational, and aesthetic value to humans.

Riparian areas are sensitive to significant disturbance patterns. Excessive livestock grazing, agriculture, large-scale timber removal, road building, urban development, and recreation are among the uses of riparian areas and the adjacent watersheds that can negatively impact riparian and aquatic ecosystems. Military installations present both unique and common stressors impacting ecosystem sustainability. The cumulative effects of such disturbances can result in a significant reduction of ecosystem functionality and associated benefits.

# SERDP CORE STATEMENT OF NEED FOR FY01 - CONSERVATION NEW START

## MARINE MAMMAL MONITORING

**OBJECTIVE:** The goal of this statement of need (SON) is to determine the feasibility of monitoring the behavior of, and measuring the near- and long-term effects of various Navy and Defense tests, sonar system evaluations, and ocean experiments on marine mammals in regional ocean areas. Proposals should address some or all of the following objectives:

- Determine the feasibility of monitoring of marine mammals in select Navy undersea ranges to determine the availability, variability and probability of detection and classification of the marine mammals.

- Develop inexpensive sensors and data processing techniques for monitoring select ocean areas to determine marine mammal presence and movement as a means to mitigate the impact of ocean experiments that use acoustic energy at levels of concern.

- Develop methods to determine the near- and long-term effects of various Naval activities and experiments that emit acoustic energy at levels of concern on marine mammals in their natural ocean environment in select ocean areas of Navy interest.

**BACKGROUND:** Presently, the Department of Defense (DoD) and the Navy have only a limited capability to monitor marine mammals in the oceans. The systems that are used to collect the data and the associated monitoring techniques were generally designed for other Navy purposes. Although some of the technology used are capable of monitoring location of marine mammals in their natural environment, the systems are too expensive to use, too bulky, and none of them have been fully evaluated to measure their effectiveness in monitoring marine mammals. There are no techniques for measuring the long-term impacts on marine mammals from Navy underwater systems tests and experiments.

Navy undersea acoustic ranges, with the requisite acoustic sensors in place, provide the initial, select opportunity to address the issue of long-term effects of Navy activities on marine mammals. If it is possible to acoustically monitor marine mammal activity over much of the area of the range, then, at the most fundamental level of analysis, some appreciation can be made about the impact of Navy experiments and tests. As an example, if after some test or experiment the animals avoid a certain region where there is no physical or biological reason why they should, we can assume this unusual, unexpected behavior to be a result of the test or experiment. If marine mammal tracking is possible, even if just in clusters or herds, immediate information is available to attest the behavioral response to a test or experiment. Appropriate acoustic techniques applied to undersea acoustic ranges can provide continuous marine mammal data, day and night, in both good and foul weather and in all seasons. This will provide a capability to build replicable, long-term data on marine mammal activity in a given region.

The initial monitoring of the presence of marine mammals is ineffective, but more difficult is the assessment of what happens to that environment following some activity. A useful assessment must monitor not only the initial impact from some event, but also the behavioral effect over long periods of time. In the case of marine mammals it is essential to monitor their behavior after some anthropogentic event to observe any obvious immediate impact, and then over time, to measure any modifications to their normal behavior that is not related to natural ecological or physical environmental changes.

## SERDP SEED STATEMENT OF NEED FOR FY01 - CONSERVATION NEW START

## UNIQUE INDICATORS OF STRESS ON THREATENED AND ENDANGERED SPECIES

**OBJECTIVE:** The objective is to solicit proposals that identify unique, non-invasive indicators of stress or impact of military activities on TES. The indicators must be capable of rapidly and economically yielding thresholds of risk to TES from military impacts. Proposals responding to this SON should identify unique, non-invasive indicators of stress from military activities on TES and provide the ability to assess these indicators in an accurate and efficient manner that can be replicated for monitoring purposes at locations where target TES might be located.

Proposed techniques must be suitable to be incorporated into standard protocols for analysis and assessment of TES. Efforts should apply to a range of military stresses, and the techniques used to assess the impact(s) must be able to yield positive results along the range of military stresses. Efforts must be acceptable, both scientifically and from the perspective of the U.S. Fish and Wildlife Service as the regulator of TES.

**BACKGROUND:** The DoD must comply with the Endangered Species Act (ESA). To do so requires adequate knowledge of the numbers and locations of TES that occur on DoD installations. A U.S. Forest Service (USFS) General Technical Report (RM-241, January 1994) and a Nature Conservancy report (January 1996) indicate that the DoD has the highest number of Federally listed TES per acres managed among major Federal land managers (including National Park Service, Fish and Wildlife Service, Forest Service, and Bureau of Land Management).

Compliance with the ESA has and can adversely affect military training and testing. For example, traffic corridors are currently being used on many Army installations instead of training areas to avoid identified TES habitats. This affects training effectiveness by not allowing the military to exercise tactical decision-making during training. Given trends for faster, heavier vehicles and combined arms exercises this reduction in land available for training has become critical.

The Services must continually seek new ways to improve the availability of land for training and testing without impacting TES. To accomplish this, new methods and technologies that address maneuver training, smokes and obscurants, and noise (vehicle and blast) impacts on TES and habitat are needed. Information from these techniques can be used to define the balance between training and testing buffers that protect TES population growth while maximizing land acreage available for mission activities.

## SERDP CORE STATEMENT OF NEED FOR FY01 - POLLUTION PREVENTION NEW START

## ENVIRONMENTALLY INNOVATIVE TECHNOLOGIES FOR LOW OBSERVABLE COATINGS APPLICATIONS - REMOVAL AND REPAIR

**OBJECTIVE:** The objective of this statement of need (SON) is to develop environmentally benign applications, and removal and repair processes for electro-radiation effects coatings that meet Low Observable (LO) requirements of Department of Defense weapon systems. These specialty coatings contribute greatly to the military mission and often are enabling technologies. The proposed coating(s) application/ removal and repair technology must be addressed from a systems level and exhibit potential for lower life cycle environmental impact than the current specialty coatings processes. Field support issues (maintenance and repair) and systems' applications must be considered in the proposed effort.

The proposed technology must eliminate or significantly reduce volatile organic compounds (VOC), hazardous air pollutants (HAP), and hazardous solid or liquid components and/or waste streams. The goal is to significantly reduce VOC levels and eliminate HAP solvents. Global warming issues may be addressed, but are of secondary importance. The focus of research under this SON is the reduction or elimination of environmental liability, not performance enhancement.

**BACKGROUND:** The implementation of National Emissions Standards for Hazardous Air Pollutant (NESHAP) requirements specific to the use and removal of general aerospace coatings has fostered significant research and development for environmentally benign general aerospace coatings over the past few years. However, very little work has been done to improve LO coatings application and removal processes because they have been exempted from regulation and are not presently limited to a set amount of VOCs and/or HAPs per unit volume. However, their contribution to atmospheric releases is significant. In addition, the total VOC and HAP emissions at any individual facility or location are often locally controlled and are of major concern. LO coatings significantly contribute to these total emissions and must be addressed to ensure compliance with minimal mission impact.

Removal of LO coatings has been done primarily by sanding or through the use of high VOC solvents. Due to the hazardous material content of the coatings, and therefore the associated sand residues or dissolved residues, these residues are considered to be hazardous material. These add to the large and increasingly expensive hazardous material wastes to be stored and eventually disposed of by the depots and aircraft logistic centers. Coating removal technologies, such as waterjet, flashjet, and laser removal are promising and possess a number of advantages. However, these often have disadvantages involving such characteristics as high investment costs, extensive training, additional systems testing, and development of revised maintenance documentation. These technologies also have not been developed for use with the various small geometries associated with antennae or with base materials, such as composites or other mixed materials as may be found on radomes or new composite structures.

## SERDP CORE STATEMENT OF NEED FOR FY01 - POLLUTION PREVENTION NEW START

## REDUCED PARTICULATE MATTER (PM) EMISSIONS FOR MILITARY GAS TURBINE ENGINE APPLICATIONS

**OBJECTIVE:** Military gas turbine engines are significant source of particulate matter less than 2.5 microns in diameter ($PM_{2.5}$). The objective of this statement of need (SON) is to develop and evaluate fuel formulations/-additives and/or hardware solutions that will mitigate the formation of particulate matter (PM) in jet fuels and/or reduce particulate matter mass concentrations in the exhaust of gas turbine engines burning JP-8, JP-5, and diesel fuel. Cost-effectiveness of the approach and impact on the environment and the ability to meet DoD mission requirements will be considered critical factors. The proposed solutions shall be applicable to military engines which: (1) require wider fuel tolerance with the minimum of Diesel #1 (DF1), Diesel #2 (DF2), DFA, JetA and JP-8, including fuels of uncertain composition in overseas and emergency operations; (2) have a duty cycle including operation at light load for significant time periods; (3) operate in more harsh environments including water fording, heavy dust, and mud; and (4) have space and performance constraints, which may impact the unit's ability to meet mission requirements.

**BACKGROUND:** Fuel is one of the most expensive components of the operational and support budget of weapon systems, and the primary cost of operating commercial airliners and ground vehicles. The Department of Defense uses between 4-5 billion gallons of aviation fuel per year. Typical use of JP-8, JP-5, and diesel fuel include military aircraft, shipboard power generation gas turbine engines, and ground support equipment. JP-8 is the jet fuel that powers all Air Force aircraft except the U-2 reconnaissance aircraft. The fuel has already been made more effective by the use of one additive package, called +100. Current jet fuels (JP-8, JP-5) break down at high temperatures to form gums, varnishes and coke that can plug fuel nozzles, afterburner sprayrings and spraybars, fuel manifolds and fuel control.

Air borne particles pose health and environmental risks. Fine particulate matter is formed by condensation from the molecular species (i.e., carbon and metals) released from the fuel during combustion. This condensation results in ultrafine particles (<0.05 micrometers) which may be directly emitted and/or accumulated on larger particles (e.g., 0.3 micrometers) either in the system or in the exhaust plume. Observations indicate that when the mass of the larger particles is controlled (e.g., smoke number is reduced), the number of small particles increases substantially. However, it is unclear whether this effect is due to lack of the condensation process or some fundamental shift in the formation mechanisms. Depending on the fuel and additives used, the fine PM may contain metals either in the oxidized or the elemental state.

The high temperatures typical of diesel operation cause oxygen and nitrogen from the intake air to combine as oxides of nitrogen (NOx). NOx is an invisible, toxic gas that can form fine aerosol particles or salts which contribute to acidic precipitation (commonly known as "acid" rain, snow or fog). If engine temperature is decreased to reduce NOx, this tends to increase the amount of uncombusted fuel that may be emitted as particulate matter (PM) or gaseous hydrocarbons (HC). HC reacts with NOx and other pollutants to form ground-level ozone (smog). Ozone and PM are associated with many adverse health and welfare effects, including respiratory illness, environmental damage and visibility problems (haze).

## SERDP CORE STATEMENT OF NEED FOR FY01 - POLLUTION PREVENTION NEW START

## GASEOUS EMISSIONS AND PARTICLE FORMATION IN THE COMBUSTION ZONE FOR DOD GAS TURBINE AND DIESEL ENGINES

**OBJECTIVE:** The objective of this statement of need is to develop a better understanding of the combustion process in gas turbine and diesel engines to improve the predictability of polycyclic aromatic hydrocarbon (PAH) formation and to better understand the role of PAHs in soot formation. This knowledge is intended to permit the prediction of the formation of all particulate matter below 10 micrometers. Any computer models developed to support this effort must be compatible with existing computational fluid dynamic models of engines and be applicable to military engines which: (1) require wider fuel tolerance with the minimum of Diesel #1 (DF1), Diesel #2 (DF2), DFA, JetA and JP-8, including fuels of uncertain composition in overseas and emergency operations; (2) have a duty cycle including operation at light load for significant time periods (3) operate in more harsh environments including water fording, heavy dust, and mud; and (4) have space and performance constraints, which may impact the unit's ability to meet mission requirements.

**BACKGROUND:** The combustor is the source of emissions for gas turbine engines. Although, the size and specific design features of combustors differ considerably, they all function in a similar manner. The combustion process is very complex and is dependent upon fluid mechanics, physical chemistry, inorganic and organic chemistry, physics, and thermodynamic effects. As a result, it is very difficult to design combustors that simultaneously reduce carbon monoxide (CO) and unburned hydrocarbon (UHC) emissions at idle and nitrogen oxides and soot at full power while still maintaining high performance and operability of the engine.

There is general agreement that the pathway to soot is through the formation of chemical precursors in fuel rich regions of a combustion process. The chemical reactions leading to soot generally proceed through the formation of large molecular weight, usually aromatic, hydrocarbons, which form soot particles. The smallest soot particles observed in flames are in the range of 1 to 2 nanometers and are thought to grow by collision and surface growth, with the relative importance of the two growth mechanisms being still subject to debate. Beyond a certain point the soot particles begin to form chain-like aggregates, with primary particles generally in the range of 10 to 30 nanometers. The fractal dimension of the aggregates has been demonstrated to be about 1.7 nanometers.

Although significant progress has been made in understanding the mechanisms of the processes leading to the soot and hydrocarbons in the combustion zone of the internal combustion engines, the models are still not predictive. There are significant differences observed between the predictions of polycyclic aromatic hydrocarbons (PAH) formation and the actual formation of soot. Although progress has been made in the use of phenomenological models to predict soot formation, these models are not generally useful in detailed computational fluid dynamic modeling of engines.

## SERDP CORE STATEMENT OF NEED FOR FY01 - POLLUTION PREVENTION NEW START

## ENVIRONMENTALLY ACCEPTABLE PYROTECHNIC FORMULATIONS

**OBJECTIVE:** The objective of this program is to develop environmentally friendly pyrotechnics for Department of Defense (DoD) applications. Pyrotechnics can be grouped into six families; decoy flares, illuminating flares, colored flares, smokes (both colored and white), igniters/starters, and miscellaneous pyrotechnic items. The focus of this statement of need is to reduce the environmental effects of these devices through either (1) reformulation of the materials in the device to reduce/eliminate toxic or carcinogenic constituents or reaction products or (2) changes to manufacturing/fabrication process which reduce/eliminate the use of hazardous solvents. The proposed effort shall result in fewer inherent environmental and worker safety risks than the current processes and provide the same or improved level of performance as the current systems.

**BACKGROUND:** The risk of exposure to pyrotechnics is considered significant because they are dispersed in air and have potential to be inhaled, ingested or dermally absorbed.

Decoy flares include infrared (IR) and solid pyrophoric flares. Pyrophoric flares incorporate steel etched by caustics which present environment, safety and health hazards. The process used to conventionally manufacture decoy flare compositions uses copious amounts of acetone and hexane solvents that must be treated as a pyrotechnically contaminated hazardous waste after processing.

Illuminating flares generally contain constituents such as sodium nitrate, barium nitrate, sodium oxalate, magnesium, and binder materials that are considered to be highly toxic, as are the combustion products of barium and sodium.

Colored signaling flares may be green, yellow, red, blue or white and contain barium, strontium, potassium, sodium or other metal salts and a binder. The largest environmental issue related to colored flares is the use of hexachlorobenzene, a known carcinogen and reproductive toxicant. Hexachlorobenzene is also a hazardous air pollutant (HAP) under the Clean Air Act (CAA), a priority pollutant under the Clean Water Act (CWA), regulated under Resource Conservation Recovery Act (RCRA), a Superfund hazardous substance, and is subject to Toxic Release Inventory reporting requirements. Barium nitrate and potassium constituents and the combustion products of barium oxide, barium chloride, hydrochloric acid, hydrogen cyanide and potassium hydroxide are considered to be highly toxic.

Pyrotechnic smokes often contain red phosphorus, hexachloroethane, a variety of organic dyes, zinc oxide, potassium perchlorate, magnesium carbonate, benzanthrone and/or sodium bicarbonate. The organic dyes in the colored smokes are often the hazardous constituents of concern.

Commercial producers of igniter/starter material use proprietary formulations and processes. However, black powder-based energetics are still used in the ignition train of weapons systems. The use of lead oxide in many igniters represents a serious environmental, safety and health issue, especially upon combustion. Although igniters typically contain only 1 to 4 grams of material, there are many tens of thousand used annually in training and testing. The oxide products of combustion associated with sulfur and boron (sulfur dioxide, sulfur trioxide, hydrogen sulfide, boron oxide and boron nitride) are highly toxic. The solvents used in the manufacture of igniters are also an issue.

## SERDP SEED STATEMENT OF NEED FOR FY01 - POLLUTION PREVENTION NEW START

## ENVIRONMENTALLY BENIGN CERAMIC MATERIALS FOR DOD SYSTEMS

**OBJECTIVE:** The objective of this program is to develop innovative approaches to eliminate/reduce the use of toxic materials in the production, maintenance and repair of ceramic materials in Department of Defense (DoD) applications. The development of environmentally benign, alternative chemistries and production/repair processes for DoD ceramic materials will result in a reduction in the use of toxic ingredients, reagents and solvents associated with the manufacture and maintenance of ceramic armor and sensors. It will also reduce or eliminate the generation of toxic or hazardous waste streams. The focus of this statement of need is the development of alternative processes, not the development of alternative ceramic materials.

**BACKGROUND:** Ceramics are used extensively throughout the DoD. Their light weight, high strength, and resistance to aggressive environments makes them the materials of choice for a wide range of applications including personnel and crew seat armor, temperature resistant coatings, vehicle armor, transparent armor and radomes. In addition, a number of military unique electronic and sensor applications are also dependent upon ceramic materials. The need to deploy lighter, smaller and more lethal forces will cause DoD use of ceramics to significantly increase over the next 20 years. Service requirements for transparent ceramic armor (canopies, infrared (IR) windows, etc.), specialty ceramic coatings, and ceramic detectors/sensors are expected to see similar increases.

The DoD uses large quantities of both transparent and opaque armor ceramics in ground vehicles, rotorcraft, fixed wing aircraft and on the individual soldier. Opaque armor ceramics, such as boron carbide and alumina, are traditionally used for enhanced protection of high value assets. The typical process requires milling and pre-forming the powder in a binder solution followed by hot pressing, sintering and machining. These processes result in the production of hazardous air pollutants (HAP) that must be treated before exhausting them to the atmosphere, contamination from sintering aides, and generation of hazardous sludges of sintering agents and ceramic debris. The waste stream, per pound of product produced, includes 0.1 to 0.03 pounds of greenhouse gasses/hydrocarbons/particulates, 3 pounds of volatile organic compounds and 0.5 pounds of contaminated sludge. Approximately 6 pounds of boron carbide are used in each ballistic vest and future vehicles are each projected to use from 2 to 3 tons of ceramic for armor.

IR capability is a decisive technological advantage that is employed in almost every advanced weapon system. Current plans extend this capability to almost every combat vehicle, and to large numbers of combat soldiers. Zinc selenide is the current material of choice for windows to protect most IR sensors on military platforms. The precursors used in the production of these windows are highly toxic and alternative chemistries or processes are required to reduce both emissions and waste streams. The high cost of IR windows is attributable, in part, to low process yields and the large volume of hazardous vapor that must be treated.

## SERDP SEED STATEMENT OF NEED FOR FY01 - POLLUTION PREVENTION NEW START

## ENVIRONMENTALLY BENIGN PRODUCTION, MAINTENANCE, AND REPAIR OF MILITARY COMPOSITE STRUCTURES

**OBJECTIVE:** The objective of this program is to develop innovative approaches to eliminate or reduce the use of toxic materials in the production, maintenance and repair of Department of Defense (DoD) composite structures and minimize the generation of hazardous/toxic waste resulting from these processes. The development of environmentally benign, alternative chemistries and production/repair processes for military composite materials and structure will result in the reduction in the use of toxic ingredients, reagents and solvents associated with the manufacture and maintenance of composite materials. It will also reduce or eliminate the generation of toxic or hazardous waste streams. The focus of this statement of need is the development of alternative processes, not the development of alternative ceramic materials.

**BACKGROUND:** Polymer matrix composites are used extensively throughout the DoD. Their light weight, high strength and low corrosion properties make them the materials of choice for aircraft, electronics structures, personnel protective armors (helmets, small arms protective vests), and components on weapon, vessel and vehicle systems. Military composites are distinguished from commercial ones by three factors. (1) Applications usually require high strength for damage tolerance to military threats; these high performance resins are not widely used in the commercial marketplace. (2) Military composite components often have unique secondary military performance requirements which are addressed by resin doping. (3) Military applications often require very large parts that require unique manufacturing methods adapted from commercial practices.

The materials and processes associated with general production, remanufacture and repair of composites currently involve the use of hazardous/toxic materials. Solvents such as methyl ethyl ketone, toluene, trichloroethane, and trichloroethylene are not only used for substrate preparation during the manufacture or repair process, but also are constituents of the resin systems used. These materials become hazardous wastes upon disposal. Environmental problems are compounded by the relatively short shelf life (30 – 60 days) of several of the commonly used resins.

There is a need to reduce the emissions and waste streams associated with the production of and repair/remanufacture processes for military composites. Considering the widespread use of composites, the cost and bulk of hazardous waste disposal and hazardous air pollutants (HAP) could be greatly diminished for production and repair facilities. Each could realize savings on the order of several million dollars with respect to disposal costs. In addition, the costs associated with capture and disposal of heavy metal, volatile organic compound and HAP materials will be reduced as will potential worker exposure.

## SERDP SEED STATEMENT OF NEED FOR FY01 - POLLUTION PREVENTION NEW START

## COMPUTATIONAL CHEMISTRY METHODS FOR DEVELOPMENT OF ENVIRONMENTALLY BENIGN MATERIALS AND PROCESSES

**OBJECTIVE:** The objective of this program is to explore the potential to develop and/or use advanced computational chemistry techniques to accelerate the development of environmentally benign chemicals and/or processes to reduce Department of Defense (DoD) use of hazardous/toxic materials in its weapons systems and munitions. These techniques will reduce dependence upon the cyclic process of synthesis and test and re-synthesis and expand the potential for the development of new approaches to address DoD environmentally driven materials requirements.

SEED proposals are requested which explore the potential to develop, modify, or apply advanced computational chemistry technologies for the design of environmentally benign materials and processes. It is anticipated that this effort will yield a proof of technical concept for material and/or process design that meets both performance and environmental requirements of interest to DoD. It is anticipated that the work will also include a first order analysis of the economic and environmental impact associated with the use of the computational chemistry techniques. The proposed work may, if successful, lead to a larger program, which will extend and further develop the proposed approach to exploit its potential to address DoD environmental issues.

**BACKGROUND:** Recent developments in high-performance computing capabilities have made computational chemistry techniques a potentially viable approach to improve chemical synthesis and aid the development of environmentally advantaged materials and processes. Computational chemistry techniques may be used to greatly reduce the time and expense required for the development of environmentally benign chemicals and processes. For example, modeling techniques may provide the research foundation to support the development of alternative approaches to eliminate volatile organic compounds (VOC) and hazardous air pollutants (HAP) during the synthesis and/or processing of propellants/explosives and coatings. Developments in molecular mechanics and dynamics, quantum chemistry, as well as new algorithms for determining biological activity, the prediction of physical parameters and algorithms for the efficient use of data in large data bases allow for the potential to exploit these tools for environmentally benign material design. In addition, while computational techniques have evolved significantly, future development will continue to improve our ability to predict chemical reactivity and reaction energetics, solvation characteristics, simulation of spectra, and Quantitative Structure Activity Relationships (QSAR).

Computational chemistry can be used to predict fundamental properties of materials that provide for an estimate of performance, which results in reduced requirements for performance testing. It can also be used to determine probable reaction pathways of the materials, providing a predictive method for emissions of products into the environment. Potential applications include, but are not limited to, the design, synthesis, and processing of energetic material, structural and protective materials, and military coatings.

## SERDP SEED STATEMENT OF NEED FOR FY01 - POLLUTION PREVENTION NEW START

## ENVIRONMENTALLY BENIGN PRIMER / IGNITER SYSTEMS

**OBJECTIVE:** The objective of this statement of need is to eliminate/reduce the use of toxic materials in the manufacture and maintenance of igniter or primer materials/systems in Department of Defense (DoD) applications. The focus of this program is to evaluate innovative approaches to reduce the environmental effects of these materials through reformulation or changes to manufacturing/fabrication processes. Alternative, non-chemical, approaches to perform the function of igniters and primers will also be considered. The proposed approach, if fully developed, should result in fewer inherent environmental and worker safety risks than the current processes and provide the same or improved level of performance as current systems.

**BACKGROUND:** Primers and igniters may contain a variety of hazardous materials including lead styphnate, lead azide, barium nitrate, barium chromate and tetracene. Primers generally contain very small amounts of energetic material, less than one tenth of a gram per item; however, there are millions of these items used annually in training and testing. Hazardous wastes associated with energetics life cycles constitute over 40% of DoD's wastes. In the current regulatory environment, the costs of managing these wastes have significantly increased the production, maintenance, and disposal costs of the required energetics materials. This led to a greater focus on attacking pollution at the source, both in the design of cleaner methods of making the current materials, and in searching for new materials that have equal or superior performance characteristics with less environmental impact.

The issues associated with the use of lead azide are typical. Lead azide, used in both igniters and detonators, is considered to be a highly polluting chemical. Its decomposition can produce lead fumes and hydrazoic acid and its toxicity has been linked to both the azomide radical and the lead. Its availability is also a readiness issue. High costs of groundwater cleanup recently resulted in the loss of the sole U.S. producer for the material. Without a domestic production base, the DoD is forced to rely on existing stockpiles that are subject to degradation and depletion. The material is used in 156 different products. As a result, there is a need to develop an alternative material or approach to duplicate its function. Azido-substituted phosphazenes are one example of highly energetic molecules that have been demonstrated on a small scale to be potentially more environmentally benign substitutes for both lead azide and lead styphnate.

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# APPENDIX F
## List of Acronyms

| | |
|---|---|
| 3D | Three-Dimensional |
| AAP | Army Ammunition Plant |
| AAR | Annular After Reactor |
| AB | After Burner |
| A/C | Aircraft |
| ACA | Air Compliance Advisor |
| ADN | Ammonium Dinitramide |
| ADPA | American Defense Preparedness Association |
| AEC | Army Environmental Center |
| AEMSS | Advanced Enclosed Mast/Sensor System |
| AFB | Air Force Base |
| AFCEE | Air Force Center for Environmental Excellence |
| AFCESA | Air Force Civil Engineering Support Activity |
| AFM | Atomic Force Microscopy |
| AFOSR | Air Force Office of Scientific Research |
| AFRL | Air Force Research Laboratory |
| AFRL/EQ | Air Force Research Laboratory/Environmental Quality |
| AFRL/MLQ | Air Force Research Laboratory/Materials Laboratory |
| AH | Attack Helicopter |
| AHPC | Army High-Performance Computing |
| AIChE | American Institute of Chemical Engineers |
| AICUZ | Air-Installation Compatible Use Zone |
| Al | Aluminum |
| ALC | Air Logistics Center |
| AMS | Aerospace Materials Specifications |
| AMT | Applied Membrane Technology, Inc. |
| ANL | Argonne National Laboratory |
| ANM | Animal Noise Monitor |
| ANSI | American National Standards Institute |
| AOP | Advanced Oxidation Process |
| AP | Ammonium Perchlorate |
| AQMD | Air Quality Management Districts |
| AQUASIM | Computer Program for the Identification and Simulation of Aquatic Systems |
| AR | After Reactor |
| ARA | Applied Research Associates |
| ARC | ARCInfo, GIS System |
| ARDEC | (U.S. Army) Armaments Research, Development & Engineering Center |
| AREP | Alternative Refrigerant Evaluation Program |
| ARL | Army Research Laboratory |
| ARM | Atmospheric Radiation Measurement |
| ARPA | Advanced Research Projects Agency |
| ARS | Agriculture Research Service |
| As | Aresenic |
| ASAN | Assessment System for Aircraft Noise |
| ASPA | Advanced Solid Propellant Armament |
| ASTE | Advanced Strategic and Tactical Expendables |
| ASTM | American Society for Testing and Materials |

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|---|---|
| ATD | Advanced Technology Demonstration |
| ATEDS | Advanced Technology Expendables and Dispenser System |
| ATLAS | Advanced Testing Line for Actinide Separations |
| ATOFMS | Aerosol Time of Flight Mass Spectrometer |
| ATR | Automated Target Recognition |
| ATR-FTIR | Attenuated Total Reflectance Fourier Transform Infrared Spectrometry |
| ATRP | Automatic Target Recognition Processor |
| ATTACC | Army Training and Testing Area Carrying Capacity |
| BAA | Broad Agency Announcement |
| BAAP | Badger Army Ammunition Plant |
| BACT | Best Available Control Technology |
| BBR | Badlands Bombing Range |
| BDC | Background Data Center |
| BDK | Batch Design Kit |
| BLM | Bureau of Land Management |
| BMP | Best Management Practice |
| BOD | Biological Oxygen Demand |
| BRAC | Base Realignment and Closure |
| BSAA | Boric-Sulfuric Acid Anodizing |
| BTEX | Benzene, Toluene, Ethylbenzene, and Xylene |
| BTU | British Thermal Unit |
| CA | Coupling Agent |
| CAA | Chromic Acid Anodizing |
| CAA | Clean Air Act |
| CAAA | Clean Air Act Amendments |
| CAH | Chlorinated Aliphatic Hydrocarbon |
| CAME | Clean Agile Manufacturing of Energetics |
| CAMIS | Computerized Airborne Multicamera Imaging System |
| CARB | California Air Resources Board |
| CARC | Chemical Agent Resistant Coating |
| CATS | Controlled Archeological Test Site |
| CAV | Composite Armored Vehicle |
| CBC | Construction Battalion Center |
| CCAC | Close Combat Armament Center |
| CCAD | Corpus Christi Army Depot |
| CCC | Chromate Conversion Coatings |
| CCD | Charge Coupled Devices |
| CCRT | Center for Conservation Research & Technology |
| Cd | Cadmium |
| cDCE | cic-1,2-dichloroethene |
| CDF | Confined Disposal Facility |
| CE | Civil Engineering |
| CEMS | Continuous Emissions Monitoring System |
| CER | Center for Environmental Research |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (called Superfund) |
| CERL | (USACE, ERDC) Construction Engineering Research Laboratory |
| CFC | Chlorofluorocarbon |
| CFD | Computational Fluid Dynamics |
| CHILD | Channel-Hillslope Integrated Landscape Development |
| CHPPM | Center for Health Promotion and Preventive Medicine |

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|---|---|
| CHSSI | Common High-Performance Scalable Software Initiative |
| CL-20 | Hexanthrohexaazaisowurtzitane |
| CLEO | Conference on Lasers and Electro- Optics |
| CLNAWS | China Lake Naval Air Weapons Station |
| ClOx | Chlorine Oxide |
| ClRB | Perchlorate-Reducing Bacteria |
| CMS | Cylindrical Magnetron Sputtering |
| CNO | Chief of Naval Operations |
| CO | Carbon Monoxide |
| CODEHOP | Consensus- Degenerate Hybrid Oligonucleotide Primers |
| COPC | Chemicals of Potential Concern |
| COTS | Commercial-off-the-Shelf |
| CP | Compliance (SERDP Thrust Area) |
| CPAT | Corrosion Prevention Advisory Teams |
| CPC | Corrosion Prevention Compound |
| CPT | Cone Penetrometer |
| Cr | Chromium/Chromates |
| CRADA | Cooperative Research and Development Agreement |
| CRREL | (USACE, ERDC) Cold Regions Research and Engineering Laboratory |
| CRS | Corona Radical Shower |
| CS | Conservation (SERDP Thrust Area) |
| CT | Carbon Tetrachloride |
| CT | Computed Tomography |
| CTC | Control Technology Center |
| CTIO | Coatings Technology Integration Office |
| Cu | Copper |
| CU | Cleanup (SERDP Thrust Area) |
| CW | Continuous Wave |
| CWA | Clean Water Act |
| CZARA | Coastal Zone Act Reauthorization Amendment |
| DAF | DNA Amplification Fingerprint |
| DALM | Diazoluminomelanin |
| DARPA | Defense Advanced Research Projects Agency |
| DC | Direct Current |
| DCA | Dichloroacetic Acid |
| DCA | Dichloroethane |
| DCA | Dynamic Contact Angle Analyzer |
| DCE | Dichloroethylene |
| DDR&E | Director, Defense Research and Engineering |
| DECIM | Defense Environmental Corporate Information Management |
| DEM/VAL | Demonstration/Validation |
| DENREC | Delaware Department of Natural Resources and Environmental Control |
| DERA | Defense Environmental Restoration Account |
| DESCIM | Defense Environmental Security Corporate Information Management |
| DETRS | DoD Environmental Technology Requirements Strategy |
| DFA | Difluoroamino |
| DFSP | Defense Fuel Supply Point |
| DFSS | Dedicated Feedstock Supply Systems |
| DGGE | Denaturing Gradient Gel Electrophoresis |
| DHR | Directional Hemispherical Reflectance |
| DLA | Defense Logistics Agency |
| DMA | Differential Mobility Analyzers |

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|---|---|
| DMMF | Developmental Manufacturing and Modification Facility |
| DMMP | Dimethylmethylphosphonate |
| DNA | Defense Nuclear Agency |
| DNA | Deoxyribonucleic Acid |
| DNAPL | Dense Non-Aqueous Phase Liquid |
| DNB | Dinitrobenzene |
| DNL | Dry Low NOx |
| DNT | Dinitrotoluene |
| DNTS | Dover National Test Site |
| DOC | Dissolved Organic Carbon |
| DoD | Department of Defense |
| DOE | Department of Energy |
| DOI | Department of the Interior |
| DOM | Dioctyl Maleate |
| DPG | Dugway Proving Ground |
| DRE | Destruction and Removal Efficiency |
| DTPA | Diethylenetriaminepentaacetic acid |
| DUECC | Defense Utility Energy Coordinating Council |
| DUSD(ES) | Deputy Under Secretary of Defense for Environmental Security |
| | |
| EA | Environmental Assessment |
| EAE | Environmentally Acceptable Endpoint |
| EAM | Effective Area Model |
| ECIP | Energy Conservation Investment Program |
| ECMI | Ecosystem Characterization and Monitoring Initiative |
| ECO-SSL | Ecological Soil Screening Levels |
| ECP | Engineering Change Proposal |
| ECU | Environmental Control Unit |
| EDYS | Ecological Dynamics Simulation |
| EIS | Electrochemical Impedance Spectroscopy |
| EIS | Environmental Impact Statement |
| EM | Electromagnetic |
| EM | Environmental Management |
| EMAA | Encapsulated Micron Aerosol Agents |
| EMAP | Environmental Monitoring and Assessment Program |
| EMI | Electromagnetic Induction |
| EO | Electro-Optic |
| EO | Executive Order |
| EPA | Environmental Protection Agency |
| EPCRA | Emergency Planning and Community Right-to-Know Act |
| EPRI | Electric Power Research Institute |
| EQT | Environmental Quality Technology Program |
| ERA | Ecological Risk Assessment |
| ERAP | Environmental Risk Assessment Program |
| ERDC | (USACE) Engineer Research and Development Center |
| ERDEC | (U.S. Army) Edgewood Research, Development and Engineering Center |
| ERPM | Emission Reduction Planning Model |
| ESA | Endangered Species Act |
| ESD | Electro-Spark Deposition |
| ESII | Enviroenergy Systems International, Inc. |
| ESMB | Explosive Standoff Minefield Breecher |
| ESTCP | Environmental Security Technology Certification Program |

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|---|---|
| ETH | Ethene |
| EXCEL | Experimental Chloride Extraction Line |
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| FAA | Federal Aviation Administration |
| FBR | Fluidized Bed Reactor |
| FDEM | Frequency Domain Electromagnetic |
| Fe | Iron |
| FEDS | Federal Energy Decision Screening |
| FEMP | Federal Energy Management Program |
| FFCA | Federal Facilities Compliance Act |
| FFP | Full-Flow Processor |
| FIBRC | Federal Integrated Biotreatment Research Consortium |
| FIC | Fluoroiodocarbon |
| FID | Free-Induction Decay |
| FORS | Fiber Optic Raman Sensor |
| FOX | Fluoroalkoxymethyl-3methyl-Oxetane |
| FPD | Freezing Point Depressant |
| FTS | Fourier Transform Spectrometer |
| FUDS | Formerly Used Defense Sites |
| FWPPCA | Federal Water Pollution Prevention and Control Act |
| | |
| GAC | Granular Activated Carbon |
| GC | Gas Chromatography |
| GCDIS | Global Change Distributed Information System |
| GC/FID | Gas Chromatography/Free Induction Decay |
| GC/MS | Gas Chromatography/Mass Spectrometry |
| GCMS | Gas Chromatography Coupled Mass Spectroscopy |
| GE | General Electric |
| GEM | Navy Green Energetics Manufacturing Program |
| GEM | Genetically Engineered Microorganisms |
| GIS | Geographic Information System |
| GMS | Groundwater Modeling System |
| GO | Genetic Optimization |
| GOCO | Government-Owned/Contractor-Operated |
| GOES | Geostationary Operational Environmental Satellites |
| GPR | Ground-Penetrating Radar |
| GPS | Global Positioning System |
| GRASS-PRISM | Geographic Resource Analysis Support System - Planning and Resource Integration Stewardship Model |
| GRFL | Groundwater Remediation Field Laboratory |
| GSE | Ground Support Equipment |
| GUI | Graphical User Interface |
| GV | Grassland Value Function |
| GWP | Global Warming Potential |
| | |
| $H_2$ | Hydrogen |
| HAP | Hazardous Air Pollutant |
| HAZMAT | Hazardous Materials |
| HAZMIN | Hazardous Waste Minimization |
| HBNQ | High-Bulk-Density Nitroguanidine |
| HC | Hydrocarbon |
| HCAT | Hard Chrome Alternatives Team |
| HCFC | Hydrochlorofluorocarbon |

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|---|---|
| HF | Hydrogen Fluoride |
| HFBA | Hierarchical Foreground Background Analysis |
| HFC | Hydrofluorocarbon |
| HMT | High Mesa Technologies |
| HMX | Octahydro-1,3,5,7-Tetranitro 1,3,5,7-Tetrazocine |
| HOPS | Heuristic Optimized Processing Systems |
| HPLC | High Performance Liquid Chromatography |
| HRV | Historic Range in Variation |
| HSI | Hyperspectral Imaging |
| HSRC | Hazardous Substance Research Center |
| HUD | Department of Housing and Urban Development |
| HVLP | High Volume Low Pressure |
| HVOF | High-Velocity Oxygen Fuel |
| HVTS | High Velocity Thermal Spray |
| HW | Hazardous Wastes |
| HWRC | Hazardous Waste Research Center |
| | |
| IAAP | Iowa Army Ammunition Plant |
| IBEAM | Installation Baseline Energy Analysis Model |
| ICA | Incremental Cost Analysis |
| ICAO | International Civil Aviation Organization |
| ICUZ | Installation Compatible Use Zone |
| ID | Internal Diameter |
| IDIF | Integrated Diffuser Injector Flameholder |
| IDLAMS | Integrated Dynamic Landscape Analysis and Modeling System |
| IHPTET | Integrated High Performance Turbine Engine Technology |
| IMC | Intermetallic Compound |
| INEL | Idaho National Engineering Laboratory |
| InGaAs | Indium Gallium Arsenide |
| InSb | Indium Antimony |
| INT | Iodonitrotetrazolium Chloride |
| IPD | Integrated Product Development |
| IPM | Integrated Pest Management |
| IPPD | Integrated Product/Process Development |
| IPR | In-Progress Review |
| IPSC | Interagency Perchlorate Steering Committee |
| IPT | Integrated Product Team |
| IR | Infrared |
| IRIS | Integrated Risk Information System |
| IRP | Installation Restoration Program |
| ISCT | In-Situ Chemical Treatment |
| ITAM | Integrated Training Area Management |
| IUSS | Integrated Undersea Surveillance System |
| IVD | Ion Vapor Deposition |
| IWTP | Industrial Waste Treatment Plants |
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| JASPPA | Joint Acquisition and Sustainment Pollution Prevention Activity |
| JDEP | Joint Depot Environmental Panel |
| JEMP | Joint Engineers Management Panel |
| JETC | Jet Engine Test Cell |
| JG-PP | Joint Group on Pollution Prevention |
| JP-8 | Type 8 Jet Fuel |
| JPG | Jefferson Proving Ground |

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|---|---|
| KBB | Karner Blue Butterfly |
| | |
| LAAP | Louisiana Army Ammunition Plant |
| LAMS | Laser Ablation Mass Spectroscopy |
| LANDSAT | Land Remote-Sensing Satellite |
| LANL | Los Alamos National Laboratory |
| LBCC | Land Based Carrying Capacity |
| LC | Laboratory Combustor |
| LCA | Life Cycle Assessment |
| LCAAP | Lake City Army Ammunition Plant |
| LCAD | Life Cycle Assessment and Design |
| LCED | Life Cycle Engineering and Design |
| LCI | Life Cycle Inventory |
| $LCO_2$ | Liquid $CO_2$ |
| LCTA | Land Condition Trend Analysis |
| LHM | Lead-Based Paint Hazard Management System |
| LIBS | Laser-Induced Breakdown Spectroscopy |
| LIF | Laser-Induced Fluorescence |
| LIN | Liquid Nitrogen |
| LIS | Laser Ignition System |
| LLNL | Lawrence Livermore National Laboratory |
| LMS | Land Management System |
| LNAPL | Light Non-Aqueous Phase Liquid |
| LO | Low Observable |
| LOVA | Low Vulnerability Ammunition |
| LRS&T | Long Range Science and Technology Program |
| LTM | Long-Term Monitoring |
| LTTU | Long-Term Test Apparatus |
| | |
| M&S | Modeling and Simulation |
| MADOM | Magnetic and Acoustic Detection of Mines |
| MAJCOM | Major Commands |
| MALDI | Matrix Assisted Laser Desorption Ionization |
| MARPOL | International Maritime Organizations Marine Pollution Convention |
| MARS | Mobile Analytical Reconnaissance System |
| MAS | Millimeter-Wave Atmospheric Sounder |
| MB/MS | Molecular Beam/Mass Spectrometric |
| MBT | Membrane BioTreatment |
| MCAGCC | Marine Corps Air-Ground Combat Center |
| MCB | Marine Corps Base |
| MCFC | Molten Carbonate |
| MCRA | Material/Chemical Risk Assessment |
| MeCl | Methylene Chloride |
| MEK | Methyl Ethyl Ketone |
| MF-EMI | Medium Frequency Electromagnetic Induction |
| MFR | Monthly Financial Reporting |
| MIBK | Methyl Isobutyl Ketone |
| MIC | Metastable Intermolecular Composites |
| MIDAS | Munitions Items Disposal Action System |
| MIPR | Military Interagency Purchase Request |
| MIT | Massachusetts Institute of Technology |
| MLFMA | Multi-Level Fast-Multipole Algorithm |
| MM | Modifier Molecules |

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|---|---|
| MMATS | Marine Mammal Acoustic Tracking System |
| MMMS | Mobile Meteorological Measurement System |
| MMPA | Marine Mammals Protection Act |
| MMRP | Marine Mammal Research Program |
| Mn | Manganese |
| MOA | Memorandum of Agreement |
| MODIS | Moderate-Resolution Imaging Spectroradiometer |
| MOI | Multiorifice Impactors |
| MoM | Method of Moment |
| MOSFET | Metal-Oxide Semiconductor Field-Effect Transistor |
| MOU | Memorandum of Understanding |
| MPC | Mobile Power Center |
| MPN | Most Probable Number |
| MRI | Magnetic Resonance Imaging |
| MR/H | Mine Reconnaissance/Hunter |
| mRNA | Messenger Ribonucleic Acid |
| MRTFB | Major Range and Test Facility Base |
| MSS | Multispectral Scanner |
| MT3D | Modular Transport in 3D |
| MTADS | Multi-Sensor Towed Array Detector System |
| MTBE | Methyl Tertiary Butyl Ether |
| MTR | Military Training Routes |
| MTV | Magnesium-Teflon-Viton |
| MUC | Military-Unique Contaminants |
| MUDSS | Mobile Underwater Debris Survey System |
| MWCO | Molecular Weight Cutoff |
| MWO | Modification Work Order |
| | |
| $N_2$ | Nitrogen |
| NA | Natural Attenuation |
| NAAQS | National Ambient Air Quality Standard |
| NAC | Nitro Aromatic Compound |
| NADEP | Naval Aviation Depot |
| NADPH | Reduced Nicotinamide Adenine Dinucleotide Phosphate |
| NAGPRA | Native American Grave Protection and Repatriation Act |
| NAPL | Non-Aqueous Phase Liquid |
| NAS | Naval Air Station |
| NASA | National Aeronautics and Space Administration |
| NATO | North Atlantic Treaty Organization |
| NATS | Natural Attenuation Test Simulator |
| NAVSEA | Naval Sea Systems Command |
| NAX | Natural Attenuation of Explosives |
| NBS | National Biological Survey |
| NC | Nitrocellulose |
| NCBC | Navy Construction Battalion Center |
| NCIBRD | National Center for Integrated Bioremediation Research and Development |
| NCMS | National Center for Manufacturing Sciences |
| NDCEE | National Defense Center for Environmental Excellence |
| NDE | Nondestruction Evaluation |
| NDFT | Non-Local Density Functional Theory |
| NDI | Nondestructive Inspection |
| NDI | Non-Developmental Item |
| NED | National Environmental Database |

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|---|---|
| NEETC | National Environmental Education and Training Center |
| NEPA | National Environmental Policy Act |
| NERL | National Exposure Research Laboratory |
| NESHAP | National Emissions Standards for Hazardous Air Pollution |
| NETTS | National Environmental Technology Test Site |
| NFESC | Naval Facilities Engineering Services Center |
| NG | Nitroguanidine |
| NGB | National Guard Bureau |
| NCERQA | National Center for Environmental Research and Quality Assurance |
| NCSA | National Center for Super Computers |
| NGP | Next Generation Fire Suppression Technology Program |
| NHPA | National Historic Preservation Act |
| Ni | Nickel |
| NIST | National Institute of Standards and Technology |
| NLCR | Nonlinear Continuum Regression |
| NLOS | Non Line-of-Sight |
| NMERI | New Mexico Engineering Research Institute |
| NMP | N-Methyl-Pyrolidone |
| NMR | Nuclear Magnetic Resonance |
| NN | Neural Network |
| NOAA | National Oceanic and Atmospheric Administration |
| NOP | Nebraska Ordnance Plant |
| NOV | Notice of Violation |
| NOx | Nitrogen Oxide |
| NPDES | National Pollutant Discharge Elimination System |
| NPS | National Park Service |
| NQ | Nitroguanidine |
| NRC | National Research Council |
| NRCS | National Resource Conservation Service |
| NRHP | National Register of Historic Places |
| NRL | Naval Research Laboratory |
| NRMRL | National Risk Management Research Laboratory |
| NSPS | New Source Performance Standards |
| NSWC | Naval Surface Warfare Center |
| NSWC-IHD | Naval Surface Warfare Center - Indian Head Division |
| NTIS | National Technical Information Service |
| NTL | National Test Location |
| NTP | Non-Thermal Plasma |
| NUFT3D | Non-Isothermal Unsaturated/Saturated F&T in 3D |
| OB/OD | Open Burning/Open Detonation |
| OC-ALC | Oklahoma City Air Logistics Center |
| ODC | Ozone Depleting Chemicals |
| ODP | Ozone Depleting Potential |
| ODS | Ozone Depleting Substances |
| ODUSD(ES) | Office of the Deputy Under Secretary of Defense for Environmental Security |
| OEM | Original Equipment Manufacturer |
| OEW | Ordnance Explosive Wastes |
| ONI | Office of Naval Intelligence |
| ONR | Office of Naval Research |
| OO-IDLAMS | Object-Oriented Integrated Dynamic Landscape Analysis and Modeling System |
| OPC | Optical Particle Counters |
| OPNAV | Naval Operations, Headquarters Staff (Pentagon) |

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|---|---|
| OPNAVINST | Naval Operations Instruction |
| ORD | Office of Research and Development |
| ORNL | Oak Ridge National Laboratory |
| OS3D | Operator Splitting in 3D |
| OSHA | Occupational Safety and Health Administration |
| OSU | Ohio State University |
| OTD | Office of Technology Development |
| OWS | Oil/Water Separators |
| PAA | Phosphoric Acid Anodize |
| PAFC | Phosphoric Acid Fuel Cells |
| PAH | Polycyclic Aromatic Hydrocarbon |
| PAS | Photoelectric Aerosol Sampler |
| PAS | Polyalkyl Sulfone |
| Pb | Lead |
| PBG | Propellant Burning Ground |
| PBR | President's Budget Request |
| PBPK | Physiologically-Based Pharmacokinetic |
| PCA | Tetrachloroethane |
| PCB | Polychlorinated Biphenyls |
| PCE | Perchloroethylene (tetrachloroethylene) |
| PCR | Polymerase Chain Reaction |
| PDD | Perfluoro Dimethyl Dioxol |
| PDD-TFE | Perfluoro Dimethyl Dioxol Copolymer with Tetrafluoro Ethylene |
| PDM | Programmed Depot Maintenance |
| PED | Photoacoustic Elemental Device |
| PED | Photoelectric Detector |
| PE-ECD | Photoemissive Electron Capture Detector |
| PE-IMS | Photoemissive Ion Mobility Spectrometer |
| PEO | Program Executive Officer |
| PEO/FAS | Program Executive Officer for Field Artillery Systems |
| PEP | Propellants, Explosives, Pyrotechnics |
| PG | Propylene Glycol |
| PI | Principal Investigator |
| PID | Photoionization Detector |
| PLIBS | Portable Laser-Induced Breakdown Spectroscopy |
| PM | Particulate Matter |
| PM | Program Manager |
| PMB | Plastic Media Blasting |
| PMC | Polymer-Matrix Composite |
| PNL | Pacific Northwest Laboratory |
| PNN | Probabilistic Neural Network |
| PNW | Pacific Northwest |
| POAM | Polar Ozone and Aerosol Monitor |
| POL | Petroleum, Oil, Lubricants |
| POSS | Poly(oligosilsesquioxane) |
| PP | Pollution Prevention (SERDP Thrust Area) |
| ppb | Parts per Billion |
| PPLN | Periodically-Poled, Lithium Niobate |
| PRB | Permeable Reactive Barrier |
| PTFE | Polytetrafluoroethylene |
| PTT | Platform Transmitter Terminals |
| PVD | Physical Vapor Deposition |

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|---|---|
| QA/QC | Quality Assurance/Quality Control |
| QMP | Quality Management Plan |
| QSAR | Quantitative Structural Activation Reaction |
| | |
| R&D | Research and Development |
| RABITT | Reductive Anaerobic Biological In-Situ Treatment Technology |
| RACER | Remedial Action Cost Engineering and Requirements |
| RAIDS | Remote Atmospheric and Ionospheric Detection System |
| RAM | Radar Absorbing Materials |
| RASS | Radio Acoustic Sounding System |
| RBCA | Risk-Based Corrective Action |
| RCI | Rapid Commercialization Initiative |
| RCRA | Resource Conservation and Recovery Act |
| RCW | Red-Cockaded Woodpecker |
| RDBMS | Relational Database Management System |
| RDT&E | Research, Development Test & Evaluation |
| RDX | Hexahydro-1,3,5-trinitro-1,3,5-triazine |
| REEP | Renewable and Energy Efficiency Planning |
| RfD | Reference Dose |
| RFMSS | Range Facilities Management Support System |
| RMA | Rocky Mountain Arsenal |
| RMS | Root Mean Square |
| RNA | Ribonucleic Acid |
| ROD | Record of Decision |
| RQL | Rich- Burn, Quick-Quench, Lean-Burn |
| RREL-EPA | Risk Reduction Engineering Laboratory - Environmental Protection Agency |
| RT-PCR | Reverse Transcriptase-Polymerase Chain Reaction |
| RTDF | Remediation Technologies Development Forum |
| RTG | Room Temperature Gradiometer |
| RTV | Room Temperature Vulcanizing |
| RUSLE | Revised Universal Soil Loss Equation |
| | |
| S&T | Science and Technology |
| S-O&CS | Smokes, Obscurants & Chemical Simulant Agents |
| SAB | Scientific Advisory Board |
| SAE | Society of Automotive Engineers |
| SAGE | Solvent Alternatives Guide |
| SALSA | Semi-Arid Land Surface Atmosphere |
| SANS | Small Angle Neutron Scattering |
| SAPT | Symmetry Adapted Perturbation Theory |
| SAR | Structural Activity Relationships |
| SAR | Synthetic Aperture Radar |
| SASW | Spectral Analysis of Surface Wave |
| SAVI | Soil-Adjusted Vegetation Index |
| SBAA | Sulfuric-Boric Acid Anodize |
| SBIR | Small Business Innovation Research |
| SBR | Sequential Batch Reactors |
| SCAMP | Subsurface Cleanup and Mobilization Processes |
| SCAPS | Site Characterization and Analysis Penetrometer System |
| SCF | Supercritical Fluid |
| SCFE | Supercritical Fluid Extraction |
| SCR | Selective Catalytic Reduction |
| SCM | Source Characterization Model |

| | |
|---|---|
| SCWO | Supercritical Water Oxidation |
| SEAM3D | Sequential Electron Acceptor Model in 3D |
| SEED | SERDP Exploratory Development |
| SEM | Scanning Electron Microscope |
| SEMP | SERDP Ecosystem Management Program |
| SERB | Solvent Extraction Residual Bioremediation |
| SERDP | Strategic Environmental Research and Development Program |
| SERS | Surface Enhanced Raman Sensor |
| SF | Supercritical Fluid |
| SFC | Specific Fuel Consumption |
| SFE | Supercritical Fluid Extraction |
| SHDS | Solvent Handbook Data System |
| SHS | Self-Propagating, High-Temperature Synthesis |
| SiC | Silicon Carbide |
| SIFDT | Selected Ion Flow-Drift Tube |
| SIMWE | Simulated Water Erosion |
| SKP | Scanning Kelvin Probe |
| SLPM | Standard Liters Per Minute |
| SMCA | Single Manager for Conventional Ammunition |
| SMPS | Scanning Mobility Particle Sizer |
| Sn | Tin |
| SNAP | Significant New Alternatives Policy |
| SNL | Sandia National Laboratory |
| SNRM | Strategic Natural Resources Management |
| $SO_2$ | Sulfur Dioxide |
| SODS | Seismic Ordnance Detection System |
| SON | Statement Of Need |
| SOP | Standard Operating Procedure |
| SOx | Sulfur Oxide |
| SPME | Solid-Phase Microextraction |
| SRS | Savannah River Site |
| SRTC | Savannah River Technology Center |
| SRTZ | Sequence of Reactive Treatment Zones |
| STR | Synthetic Tandem Repeat |
| SVE | Soil Vapor Extraction |
| SWB | Site Water Balance |
| TAC | Technical Advisory Committee |
| TACOM | (U.S. Army) Tank-Automotive & Armaments Command |
| TAMU | Texas A&M University |
| TAP | Technical Advisory Panel |
| TARA | (DoD Environmental) Technology Area Review & Assessment |
| TCA | Trichloroacetic Acid |
| TCA | Trichloroethane |
| TCE | Trichloroethylene |
| TCLP | Toxicity Characteristic Leachate Procedure |
| TD | Total Dissolved |
| TDL | Tunable Diode Laser |
| TDP | Technology Development Plan |
| TDS | Total Dissolved Solids |
| TEC | (USACE, ERDC) Topographic Engineering Center |
| TEM | Technology Exchange Meeting |
| TES | Threatened and Endangered Species |

| | |
|---|---|
| TES | Threatened, Endangered, and Sensitive |
| TET | Tetryl |
| TETAT | Technology Education and Training Advisory Taskforce |
| Tg | Transition Temperature |
| TIPPP | Tidewater Interagency Pollution Prevention Program |
| TIR | Thermal Infrared |
| TIWET | The Institute for Wildlife and Environmental Toxicology |
| TL | Transmission Loss |
| TM | Landsat Thematic Mapper |
| TLM | Test Location Manager |
| TMDL | Total Maximum Daily Limit |
| TMS | Thematic Mapper Simulator |
| TNAZ | Tri-Nitro Azetidine |
| TNB | Trinitrobenzene |
| TNT | Trinitrotoluene |
| TOF-SIMS | Time of Flight Secondary Ion Mass Spectrometry |
| TPE | Thermoplastic Elastomer |
| TRI | Toxic Release Inventory |
| TRU | Transuranic Radioactive Waste |
| TSVP | Thermal Spray Vitrification Process |
| TTAWG | Technology Thrust Area Working Group |
| TTU | Texas Technological University |
| TVC | Trapped Vortex Combustor |
| | |
| UB | Ultra Broadband |
| UC | University of California |
| UFA | Unsaturated Flow Apparatus |
| UFAL | Ultra-Fine Aluminum |
| UHC | Unburned Hydrocarbons |
| UM | University of Minnesota |
| UNDEERC | University of North Dakota Energy and Environmental Research Center |
| UNDS | Uniform National Discharge Standards |
| UNR | University of Nevada-Reno |
| USACE | United States Army Corps of Engineers |
| USAF | U.S. Air Force |
| USDA | United States Department of Agriculture |
| USFS | U.S. Forest Service |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |
| USPED | Unit Stream Power Erosion/Deposition |
| UST | Underground Storage Tank |
| USU | Utah State University |
| UTARNG | Utah Army National Guard |
| UTM | The University of Texas Chemical Food Simulator |
| UVRS | Ultraviolet Remote Sensing |
| UWB | Ultra Wide Band |
| UXO | Unexploded Ordnance |
| | |
| VARTM | Vacuum-Assisted Resin Transfer Molding |
| VC | Vinyl Chloride |
| VCC | Vortex Containment Combustion |
| VCPI | Visual Cleaning Performance Indicator |
| VHF | Very High Frequency |

| | |
|---|---|
| VNIR | Visible/Near Infrared |
| VNTR | Variable Number of Tandem Repeats |
| VOC | Volatile Organic Compound |
| VPISU | Virginia Polytechnic Institute and State University |
| WASI | Wide-Area Spectral Imaging |
| WEPP | Water Erosion Prediction Project |
| WEPS | Wind Erosion Prediction System |
| WHV | Wildlife Habitat Value Function |
| WIC | Water-Injection Controller |
| WPAFB | Wright Patterson Air Force Base |
| WR | Water Reducible |
| WS | Weapon Systems |
| WWW | World Wide Web |
| XAS | X-ray Absorption Spectroscopy |
| XCRIS | X-windows-based Cultural Resource Information System |
| XPS | X-ray Photo-Electron Spectroscopy |
| XRD | X-ray Diffraction |
| XRF | X-ray Fluorescence |
| XRS | X-ray Spectrometry |
| XSD | Halogen Specific Detector |
| YPG | Yuma Proving Ground |
| Zn | Zinc |

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